

**Soil and Groundwater Remediation Using**

**Risk Based Corrective Action: Case Study**

by

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## **Abstract**

Around the world, there are numerous sites that have contaminated soil and groundwater from gas station operations. The contamination concentration levels found in these sites range from high to low and are caused by various scenarios such as leaks/punctures in underground storage tanks, overfilling of storage tanks, and accidental spills, etc. The main contaminants found from these sites are predominantly total petroleum hydrocarbons (TPH), in which the main chemical constituents are benzene, toluene, ethylbenzene, and mixed xylenes (BTEX) that are known to have health and environmental effects.

This study creates a fictional scenario where a gas station located in Happy Valley – Goose Bay, NL has released a large volume of TPH contamination into the soil and groundwater in and around surrounding areas. The use of ‘Risk Based Corrective Action’ (RBCA) utilizes a tiered based consistent decision making methodology to aid in the overall optimal selection of soil and groundwater remediation technologies of soil vapour extraction and air sparging. These technologies combined together will bring the desired contaminant concentration levels back to safe conditions with zero adverse risks to human health and the surrounding environment.

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## Table of Contents

<b>Abstract.....</b>	<b>ii</b>
<b>Acknowledgements.....</b>	<b>iii</b>
<b>Table of Contents.....</b>	<b>iv</b>
<b>List of Tables.....</b>	<b>vii</b>
<b>List of Figures.....</b>	<b>ix</b>
<b>List of Equations.....</b>	<b>x</b>
<b>List of Abbreviations.....</b>	<b>xii</b>
<b>Chapter 1: Introduction.....</b>	<b>1</b>
<b>1.1 Background.....</b>	<b>1</b>
<b>1.2 Research Objective.....</b>	<b>2</b>
<b>1.3 Outline and Summary of Thesis.....</b>	<b>2</b>
<b>Chapter 2: Literature Review.....</b>	<b>6</b>
<b>2.1 Description and Effects of BTEX.....</b>	<b>6</b>
<b>2.2 Risk Based Corrective Action.....</b>	<b>11</b>
<b>Chapter 3: Happy Valley – Goose Bay – Site Scenario .....</b>	<b>16</b>

<b>Chapter 4: Site Classification and Initial Response Plan Priority Criteria.....</b>	<b>31</b>
<b>Chapter 5: Tier 1.....</b>	<b>35</b>
<b>5.1 Site Classification and Initial Response Plan.....</b>	<b>35</b>
<b>5.2 Tier 1 – Evaluation.....</b>	<b>36</b>
<b>5.3 Tier 1 – Results.....</b>	<b>48</b>
<b>6. Chapter 6: Tier 2.....</b>	<b>52</b>
<b>6.1 Site Classification and Initial Response Plan.....</b>	<b>52</b>
<b>6.2 Tier 2 – Evaluation.....</b>	<b>53</b>
<b>6.3 Tier 2 – Results.....</b>	<b>61</b>
<b>6.4 Comparison of Tier 2 to Tier 1.....</b>	<b>64</b>
<b>Chapter 7: Tier 3.....</b>	<b>66</b>
<b>7.1 Site Classification and Initial Response Plan.....</b>	<b>66</b>
<b>7.2 Tier 3 – Evaluation.....</b>	<b>67</b>
<b>7.3 Tier 3 – Results.....</b>	<b>77</b>
<b>7.4 Comparison of Tier 3 to Tier 2.....</b>	<b>80</b>
<b>Chapter 8: Remediation.....</b>	<b>82</b>
<b>8.1 Remediation Technologies.....</b>	<b>82</b>

<b>8.2 Remediation Selection for Case Study.....</b>	<b>90</b>
<b>Chapter 9: Conclusion.....</b>	<b>93</b>
<b>References.....</b>	<b>96</b>

## **List of Tables**

Table 3-1: Gas Station - Soil and Groundwater Laboratory Results.....	22
Table 3-2: Wellness Centre - Soil and Groundwater Laboratory Results.....	23
Table 3-3: Store - Soil and Groundwater Laboratory Results.....	24
Table 3-4: Residential Houses - Soil and Groundwater Laboratory Results.....	25
Table 3-5: Walking Trail - Soil and Groundwater Laboratory Results.....	26
Table 3-6: Pub - Soil and Groundwater Laboratory Results.....	27
Table 4-1: Priority 1 Scenario and Initial Response Plan.....	31
Table 4-2: Priority 2 Scenario and Initial Response Plan.....	32
Table 4-3: Priority 3 Scenario and Initial Response Plan.....	33
Table 4-4: Priority 4 Scenario and Initial Response Plan.....	34
Table 5-1: Tier 1 - RBSL Default Exposure Parameters.....	44
Table 5-2: Tier 1 - RBSL Default Soil, Building, Surface and Subsurface Parameters.....	45
Table 5-3: Tier 1 –RBSL Look-up Table for Residential Sites.....	47
Table 5-4: Tier 1 –RBSL Look-up Table for Commercial Sites.....	47
Table 6-1: Tier 2 - SSTL Exposure Parameters.....	56

Table 6-2: Tier 2 - SSTL Soil, Building, Surface and Subsurface Parameters.....	57
Table 6-3: Tier 2 – Calculated SSTL Volatilization Factors.....	58
Table 6-4: Tier 2 – Calculated SSTL Look-up Table for Residential Sites.....	60
Table 6-5: Tier 2 – Calculated SSTL Look-up Table for Commercial Sites.....	60
Table 7-1: Tier 3 – SSTL Residential Exposure Parameters.....	70
Table 7-2: Tier 3 – SSTL Residential Soil, Building, Surface and Subsurface Parameters.....	71
Table 7-3: Tier 3 – SSTL Commercial Exposure Parameters.....	72
Table 7-4: Tier 3 – SSTL Commercial Soil, Building, Surface, and Subsurface Parameters.....	73
Table 7-5: Tier 3 – Calculated SSTL Volatilization Factors.....	75
Table 7-6: Tier 3 – SSTL Look-up Table for Residential Sites.....	76
Table 7-7: Tier 3 – SSTL Look-up Table for Commercial Sites.....	77



## **List of Figures**

Figure 2-1: RBCA Process Flowchart.....	15
Figure 3-1: General Map of Exposed Areas of Concern.....	17
Figure 3-2: Location of Soil and Groundwater Samples with Labels.....	21
Figure 3-3: Conceptual Site Model.....	29
Figure 3-4: Exposure Scenario Evaluation Flowchart.....	30

## List of Equations

Equation -1: RBSL for Carcinogenic – Air Inhalation.....	36
Equation -2: RBSL for Carcinogenic – Groundwater Ingestion (Potable Water).....	37
Equation -3: RBSL for Carcinogenic – Groundwater Ambient Vapour Inhalation.....	37
Equation -4: RBSL for Carcinogenic – Surficial Soil –Ingestion of Soil, Inhalation of Vapours and Particulates, and Dermal Contact.....	37
Equation -5: RBSL for Carcinogenic – Subsurface Soil – Ambient Vapour Inhalation.....	38
Equation -6: RBSL for Carcinogenic – Subsurface Soil – Leaching to Groundwater.....	38
Equation -7: RBSL for Non-Carcinogenic – Air Inhalation .....	39
Equation -8: RBSL for Non-Carcinogenic – Groundwater Ingestion (Potable Water).....	39
Equation -9: RBSL for Non-Carcinogenic – Groundwater Ambient Vapour Inhalation.....	39
Equation -10: RBSL for Non-Carcinogenic – Surficial Soil –Ingestion of Soil, Inhalation of Vapours and Particulates, and Dermal Contact.....	40
Equation -11: RBSL for Non-Carcinogenic – Subsurface Soil – Ambient Vapour Inhalation.....	40

Equation -12: RBSL for Non-Carcinogenic – Subsurface Soil – Leaching to Groundwater.....	40
Equation -13: Volatilization Factor – Surficial Soils to Ambient Air Vapours .....	41
Equation -14: Volatilization Factor – Surficial Soils to Ambient Air Vapours .....	41
Equation -15: Volatilization Factor – Surficial Soils to Ambient Air Particles .....	41
Equation -16: Volatilization Factor – Subsurface Soils – Ambient Air.....	42
Equation -17: Leaching Factor – Subsurface Soils - Groundwater.....	42
Equation -18: Effective Diffusion Coefficient in Soil.....	42

## **List of Abbreviations**

ASTM – American Society of Testing Materials

BTEX – Benzene, Toluene, Ethylbenzene, and Mixed Xylenes

RBCA – Risk Based Corrective Action

RBSL – Risk Based Screening Levels

SSTL - Site Specific Target Levels

SVE – Soil Vapour Extraction

TPH – Total Petroleum Hydrocarbons

## **Chapter 1: Introduction**

### **1.1 Background**

There are numerous residential and commercial sites across the world that contaminated by Total Petroleum Hydrocarbons (TPH) leaks and spills which are adversely affecting the sites nearby soil and groundwater. (ATSDR, 1999) In a TPH release, the main chemicals of concern are usually BTEX which is an acronym for benzene, toluene, ethylbenzene, and mixed xylenes. (ATSDR, 1999)

Each constituent of BTEX are known to have their own respective adverse effects on human health in short and long term exposure durations with certain chemicals causing cancer. (ATSDR, 1999) Also, BTEX may enter the environment via various transport mechanisms and enter the human body via ingestion, inhalation, or dermal contact. (ATSDR, 1999)

BTEX may enter the soil and groundwater via various sources such as leaks/punctures in underground storage tanks, overfilling of storage tanks, and accidental spills, etc. (MDE, 2004) Once released into the surrounding environment, BTEX has the physical abilities to dissolve in water allowing for BTEX to migrate via groundwater. (MDE, 2004) Also, BTEX has the ability to adhere to soil particles and remain in soil for long periods of time. (MDE, 2004) Certain constituents of BTEX can easily evaporate into the ambient air, which are transported to the surrounding environment via wind. (MDE, 2004)

To protect the human health and the surrounding environment from contamination such as BTEX, the American Society for Testing Materials (ASTM) has developed a

consistent decision methodology called Risk Based Corrective Action (RBCA). (ASTM, 2015) RBCA is a tiered based process designed to optimize efficient remediation goals by measuring site characteristics versus potential human health and environmental risks. (Khan, F.I. and Husain, T., 2001) RBCA requires a site assessment, site classification, Tier 1 evaluation, Tier 2 evaluation, Tier 3 evaluation, and remedial action to enable the contaminated site to reach safe and acceptable levels. (ASTM, 2015)

RBCA assists in the optimal selection and implementation of soil and groundwater remediation technologies. (ASTM, 2015) Each of the remediation methods operate differently and are dependent on many factors to select the optimal choice. (USEPA, 1994) The soil and groundwater remediation technology selected is dependent on its degree of environmental impact, site conditions, volume of contamination area, concentration levels, cost, feasibility, stakeholder's preference, time to remediate soil and many other scenarios to create environmentally friendly conditions. (USEPA, 1994)

## **1.2 Research Objective**

The research objective is to obtain safe contaminant concentration levels, in soil and groundwater, with zero adverse risks to human health and the surrounding environment to a fictionally contaminated gas station in Happy Valley – Goose Bay, NL by the implementation of Risk Based Corrective Action (RBCA).

## **1.3 Outline and Summary of Thesis**

Chapter 1 presents the background information which briefly introduces the main chemicals of concern (BTEX) in a TPH contamination release and the transport

mechanisms involved in how BTEX enters the human body. Risk Based Corrective Action (RBCA) and the optimal selection of soil and groundwater remediation technologies are briefly introduced and described. Chapter 1 also presents the research objective and outline of thesis.

Chapter 2 presents the literature review which describes in detail about BTEX contamination and each of its respective constituents of benzene, toluene, ethylbenzene, and mixed xylenes and how it may affect the human body in acute and chronic exposures. The tiered methodology approach of RBCA is also described.

Chapter 3 describes the fictional contaminant site scenario located in Happy Valley – Goose Bay, NL where a gas station has accidentally released a large quantity of TPH into the surrounding environment. Chapter 3 describes the processes involved to aid in remediation of the contamination release through implementation of RBCA, which contains: Initial site assessment, source of contamination, determination of current use of sites, identification of chemicals of concern, location of major source of chemicals of concern and location of human receptors that could be impacted, determination of regional hydrogeological and geological characteristics, location and results of maximum concentrations of chemicals of concern in soil and groundwater, identification of potential significant transport and exposure pathways, conceptual site model and the exposure scenario evaluation flowchart.

Chapter 4 describes the site classification and initial response plan criteria which describes four different site classification priority scenarios which are ranked in severity from high to low with each scenario having its own respective initial response plan(s).

Chapter 5 describes the Tier 1 RBCA process which explains how Tier 1 is implemented and how the commercial and residential risk based screening levels (RBSL) are calculated using carcinogenic and non-carcinogenic RBSL's equations with default exposure parameters and default soil, building, surface, and subsurface parameters to develop a look-up table which is used to compare to the soil and groundwater laboratory samples collected at each contaminated site.

Chapter 6 describes the Tier 2 RBCA process which explains how Tier 2 is implemented and how the commercial and residential site specific target levels (SSTL) are calculated using carcinogenic and non-carcinogenic SSTL's equations with collected SSTL exposure parameters and collected SSTL soil, building, surface, and subsurface parameters to develop a look-up table which is used to compare to the soil and groundwater laboratory samples collected at each contaminated site.

Chapter 7 describes of the Tier 3 RBCA process which explains how Tier 3 is implemented and how the commercial and residential SSTL's are calculated using carcinogenic and non-carcinogenic SSTL's equations along with probabilistic evaluations, additional site assessment, and complicated chemical fate and transport models. The collected SSTL exposure parameters and SSTL soil, building, surface, and subsurface parameters are used to develop a look-up table which is used to compare to the soil and groundwater laboratory samples collected at each contaminated site.

Chapter 8 describes the remedial stage of RBCA where potential remediation technologies are discussed to lower the site BTEX concentrations become equal or below the Tier 3 SSTL's. Three soil and three groundwater remediation technologies are



explained in this chapter to aid in the removal of BTEX where the optimal soil and groundwater remediation technologies are selected based on various site specific factors.

Chapter 9 presents the conclusion which summarizes the presented work.

## **Chapter 2: Literature Review**

### **2.1 Description and Effects of BTEX**

Total Petroleum Hydrocarbons (TPH's) are a large group of chemical compounds containing carbon and hydrogen that originate from crude oil which is of biological decent. (ATSDR, 1999) TPH liquids have a vast range of physical properties with many having the properties of higher density with thick dark brown and/or black colour that do not evaporate easily while other TPH liquids may have a lower density with a clear or light colour that evaporate or volatilize easily. (ATSDR, 1999) Most TPH liquids are combustible in ambient air. (ATSDR, 1999)

Usually the main TPH's chemicals of concern on a contaminated site are benzene, toluene, ethylbenzene, and xylene. These chemicals of concern are usually abbreviated as BTEX and all of these chemicals may result in adverse effects on human health and have various transport mechanisms to enter the environment. (ATSDR, 1999) BTEX has the potential to enter the human body through ingestion of food and water, dermal contact and inhalation. (ATSDR, 1999)

When BTEX is released into the environment, it has the ability to leach into the soil and potentially into the groundwater. (ATSDR, 1999) It may adsorb to soil particles and remain underground for extended periods of time. (ATSDR, 1999) When BTEX is in contact with water it will float and form a thin surface film. (ATSDR, 1999) BTEX may enter potable drinking water sources and contaminate food sources with many of the people unaware of the health hazard. (ATSDR, 1999) Groundwater and surface water flow will also direct BTEX to migrate to other locations. (ATSDR, 1999) Inhalation of

BTEX is possible since it has the capability to vertically flow from the groundwater to the ground surface where will volatilize into ambient air. (ATSDR, 1999)

Benzene is a colourless, volatile, and highly flammable liquid that dissolves slightly in water. (USEPA, 2012a) It is a known human carcinogen that may negatively affect the human body in various ways over acute (short term) and chronic (long term) exposures. (USEPA, 2012a)

Benzene has the potential to enter the human body through inhalation, dermal contact, and ingestion. (ATSDR, 1999) When it is inhaled, the benzene passes through the membranes of the lungs and then enters the bloodstream. (ATSDR, 2007a) Dermal contact with benzene may result in the chemical entering the bloodstream through the skin organ. (ATSDR, 2007a) Ingestion of benzene may also result in the chemical entering the bloodstream through lining of the gastrointestinal tract. (ATSDR, 2007a) Once benzene is in the bloodstream, it may enter and remain stored in the human body's fatty tissues and bone marrow. (ATSDR, 2007a)

Acute inhalation of benzene may cause symptoms of dizziness, headaches, drowsiness, rapid heart rate, confusion, and unconsciousness. (USEPA, 2012a) Acute ingestion of benzene may create symptoms of convulsions, vomiting, sleepiness and dizziness. (USEPA, 2012a) Acute dermal exposure to benzene liquid and vapour could potentially cause blisters, irritation of eyes, skin, and upper respiratory system. (USEPA, 2012a)

Chronic exposure to benzene may cause many negative human side effects. (ATSDR, 2007a) The tissues that form blood cells may get damaged, which may cause anemia. (ATSDR, 2007a) Reproductive organs may be harmed in women and it may also create

health problems for newborns such as bone marrow damage, delayed bone formation, and low birth weight. (ATSDR, 2007a) Long term exposure may weaken the human body's immune system, which may lead to higher risks of infection and disease. (ATSDR, 2007a) Benzene may cause cancer of blood producing organs, which is called leukemia. (ATSDR, 2007a)

Toluene is a clear, colourless, flammable liquid that's dissolves slightly in water. (USEPA, 2012b) It is a non-carcinogenic chemical known to have harmful acute and chronic health effects. (USEPA, 2012b)

Toluene has the potential to enter the human body via inhalation, ingestion and dermal contact. (ATSDR, 1999) When it is inhaled it may absorb directly into the bloodstream through the lungs. (ATSDR, 2015) Ingestion of toluene may result in the chemical entering the bloodstream through the gastrointestinal tract. (ATSDR, 2015) Dermal contact from toluene may result in the chemical entering the bloodstream through the skin. (ATSDR, 2015)

Acute inhalation of toluene may result in chemical induced asthma, irritation and fluid accumulation in lungs and respiratory tract. (ATSDR, 2014) Acute ingestion of toluene may result in irritation of stomach, abdominal pain, vomiting, diarrhea, and nausea. (ATSDR, 2014) Acute dermal exposure to toluene may harm the skin and eyes. Skin contact may result in irritation, redness, and formation of blisters. (ATSDR, 2014) Eye contact with toluene may result in irritation, inflammation, and burning pain. (ATSDR, 2014) Also, inhalation and ingestion of toluene has a dramatic impact on the central nervous system resulting in symptoms of confusion, nausea, migraines, dizziness,

impaired judgement, blurry vision, loss of consciousness, and coma leading to death.

(ATSDR, 2014)

Chronic exposure to toluene has various long term effects on human health such as frequent headaches, nausea, fatigue, memory loss, appetite loss, impaired coordination, and irreversible optic nerve damage. (ATSDR, 2014) Some irreversible symptoms of chronic exposure to toluene include disorder of optic nerves and muscles, cardiovascular and renal tubular damage, and sudden death. (ATSDR, 2014) Chronic exposure may also negatively affect reproduction by newborn infants showing defects of small heads, central nervous system dysfunction, minor limb and face deformities. (ATSDR, 2014)

Ethylbenzene is a clear, colourless, flammable liquid. (ATSDR, 2010a) It is a potential carcinogenic chemical known to have harmful acute and chronic health effects. (ATSDR, 2010a)

Ethylbenzene has the potential to enter the human body via inhalation, ingestion and dermal contact. (ATSDR, 1999) Inhalation results in the chemical entering the human body rapidly through the lungs. (ATSDR, 2010a) Ingestion may result in rapid chemical absorption through the gastrointestinal tract. (ATSDR, 2010a) Dermal contact may result in ethylbenzene entering the human body through the skin. (ATSDR, 2010a)

Acute inhalation of ethylbenzene in air may result in vertigo, dizziness, and irritation of eyes and throat. (ATSDR, 2010b) Acute ingestion may cause minor stomach irritation. Dermal contact with skin and eyes may result in irritation and eye damage. (ATSDR, 2010b)

Chronic inhalation exposure to ethylbenzene may result in permanent damage to inner ear and hearing, kidney damage, and potentially cancer in kidneys, liver and lungs. (ATSDR, 2010b) Chronic ingestion may result in severe permanent damage to the inner ear. (ATSDR, 2010b) Chronic dermal contact may result severe skin irritation and skin damage. It is unknown whether or not ethylbenzene may cause birth defects. (ATSDR, 2010b)

Xylene is group of three isomers m-, o-, p- xylenes that are usually mixed together. (ATSDR, 2007b) Mixed xylenes are a colourless, flammable liquid that evaporate easily and is insoluble in water. (ATSDR, 2007b)

Xylene has the potential to enter the human body via inhalation, ingestion, and dermal contact. (ATSDR, 1999) Inhalation results in the mixed chemicals rapidly absorbing through the lungs. (ATSDR, 2007b) Ingestion may result in rapid chemical absorption through the gastrointestinal tract. (ATSDR, 2007b) Dermal contact may result in xylene entering the human body through the skin rapidly and into the bloodstream. (ATSDR, 2007b)

Acute inhalation of xylene in air may cause symptoms of headaches, dizziness, nausea, vomiting, dyspnea, abdominal pain, eyes, nose and throat irritation, short term memory loss and physical impairment. (USEPA, 2000) Acute ingestion of mixed xylenes may result in systemic toxicity. (USEPA, 2000) Dermal contact may result in inflammation, drying, scaling and irritation of the skin. (USEPA, 2000) Direct contact to the eyes may result in damage to the cornea and cause irritation. (USEPA, 2000)

Chronic exposure to mixed xylenes has shown to potentially cause headaches, fatigue, anxiety, dizziness, inability to think clearly, tremors, difficulty breathing, chest pain, increased heart rate, possible adverse liver, central nervous and kidney effects. (USEPA, 2000) Birth defects are possible through exposure to xylene by causing skeletal issues, decreased body weight, fetal resorptions, and delayed ossification. (USEPA, 2000)

## **2.2 Risk Based Corrective Action**

To protect the human health and the surrounding environment from BTEX contamination, the American Society for Testing Materials (ASTM) has developed a consistent decision methodology called Risk Based Corrective Action (RBCA). (ASTM, 2015) RBCA is a tiered based process designed to optimize efficient remediation goals by measuring site characteristics versus potential human health and environmental risks. (Khan, F.I. and Husain, T., 2001)

RBCA is a methodology where decisions are developed consistently to protect the surrounding environment and human health from contamination such as BTEX. (ASTM, 2015) RBCA is designed in tiers, each of which includes various levels of data collection and analysis. As the RBCA progresses then the assumptions from previous tiers are substituted with site specific data. (ASTM, 2015) Each tier's results are evaluated and reviewed to decide if more site specific data is required. (ASTM, 2015) RBCA requires a site assessment, site classification, Tier 1 evaluation, Tier 2 evaluation, Tier 3 evaluation, and remedial action. (ASTM, 2015)

A site assessment is required to identify the source of contaminants, classify potential human and environmental impacts and receptors, identify fate and transport exposure pathways, and collect historical information on the site and a visual inspection is recommended. (ASTM, 2015)

Site Classification of the contaminated site is required in the RBCA process. (ASTM, 2015) Contaminated sites are classified based off the data collected from the site assessment and through the crucial need to remediate the specific area. (ASTM, 2015) A contaminated site that has an immediate threat to human health and the surrounding environment will have a higher priority site classification than a site with less hazards and risks. (ASTM, 2015) Initial response actions which are necessary for each potential hazard scenario are also associated in the site classification stage and are implemented into the RBCA procedures. (ASTM, 2015) Throughout the RBCA process, the site requires reclassification as actions are implemented and more data is collected. (ASTM, 2015)

Tier 1 in the RBCA process uses an initial site assessment which is based on contaminate exposure potential, transportation of contaminants, contamination source characterization, and an evaluation report of the site characterization. (ASTM, 2015) Risk based screening levels (RBSL), which are based off conservative default parameters, are compared with the contaminant concentrations. (ASTM, 2015) If the results in Tier 1 are unacceptable due to concentration levels, time, cost, or feasibility, etc. then additional specific site data is collected to reassess the contaminated site according to Tier 2 guidelines. (ASTM, 2015) (Khan, F.I. and Husain, T., 2001) If Tier 1 results are acceptable then the site requires no further action. (ASTM, 2015)



Tier 2 in the RBCA process is implemented when the results of Tier 1 are unacceptable. (ASTM, 2015) Tier 2 utilizes site specific data instead of default values in Tier 1. The site specific data assists in obtaining site specific target levels (SSTL), which are defined through the sites physical and chemical properties, along with analytical assessment modeling. (ASTM, 2015) The site conditions are analyzed in Tier 2 to obtain achievable, reasonable, cost efficient, and environmentally friendly remedial action goals. (ASTM, 2015), (Khan, F.I. and Husain, T., 2001) If the results in Tier 2 are unacceptable then more specific site information is obtained for reassessment according to Tier 3 guidelines. (ASTM, 2015), (Khan, F.I. and Husain, T., 2001) If Tier 2 results are acceptable then the site requires no further action. (ASTM, 2015)

Tier 3 is utilized when the results of Tier 2 are unacceptable. (ASTM, 2015) Tier 3 in the RBCA process requires an in depth site assessment with the SSTL's derived from very complex site specific data and may require complicated probabilistic analysis and fate and transport models. (ASTM, 2015) If the results in Tier 3 are unacceptable then commencement of remediation is required to reduce the contaminant concentrations to acceptable levels. (ASTM, 2015) If Tier 3 results are acceptable then the site requires no further action. (ASTM, 2015)

Analytical modelling simulates dilution, degradation, advection, biodegradation, sorption and adsorption, etc. (Khan, F.I. and Husain, T., 2001) This aids to measure transport and remediation of contamination plumes in the specific site. (Khan, F.I. and Husain, T., 2001) Each model comprises of a conceptual model which represents the natural system, mathematical model, calibration of the mathematical solution to the computed natural

system, validate the accuracy of the model, and simulation derived from calibrated solution from the conceptual model. (Khan, F.I. and Husain, T., 2001)

Remedial Action in the RBCA process involves whether the concentration levels at the specific site are higher than the RBSL's or SSTL's. (ASTM, 2015) If the levels are higher, then a remedial action plan and compliance monitoring is required to reduce the potential for negative human and environmental impacts from the contaminants. (ASTM, 2015) Remedial Action is the implementation of a soil and/or groundwater remediation technique or technology to achieve the required RBSL's and SSTL's. (ASTM, 2015) Compliance monitoring ensures that the selected remediation plan is operating properly. (ASTM, 2015) The following Figure 2-1 illustrates the RBCA process flowchart.

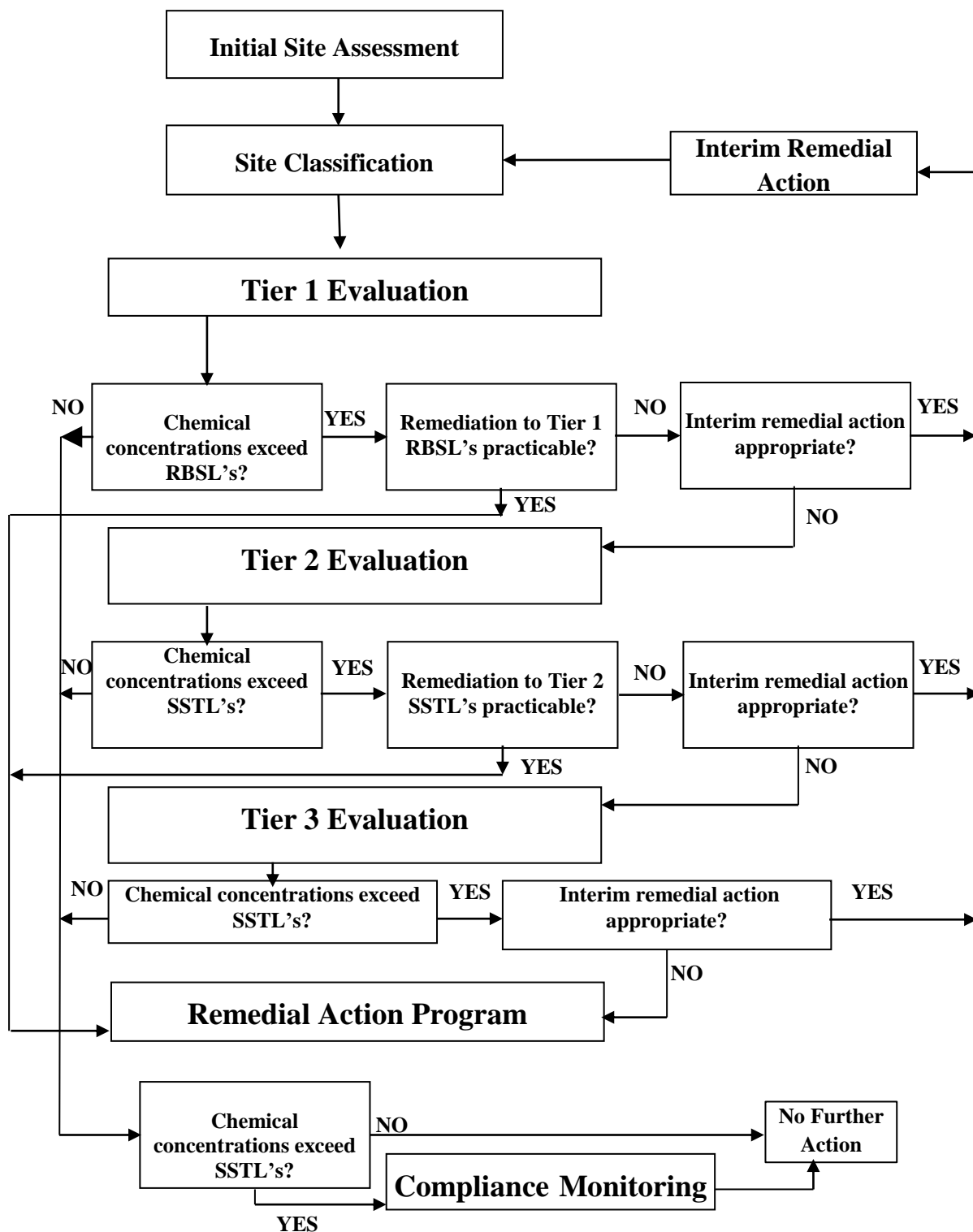


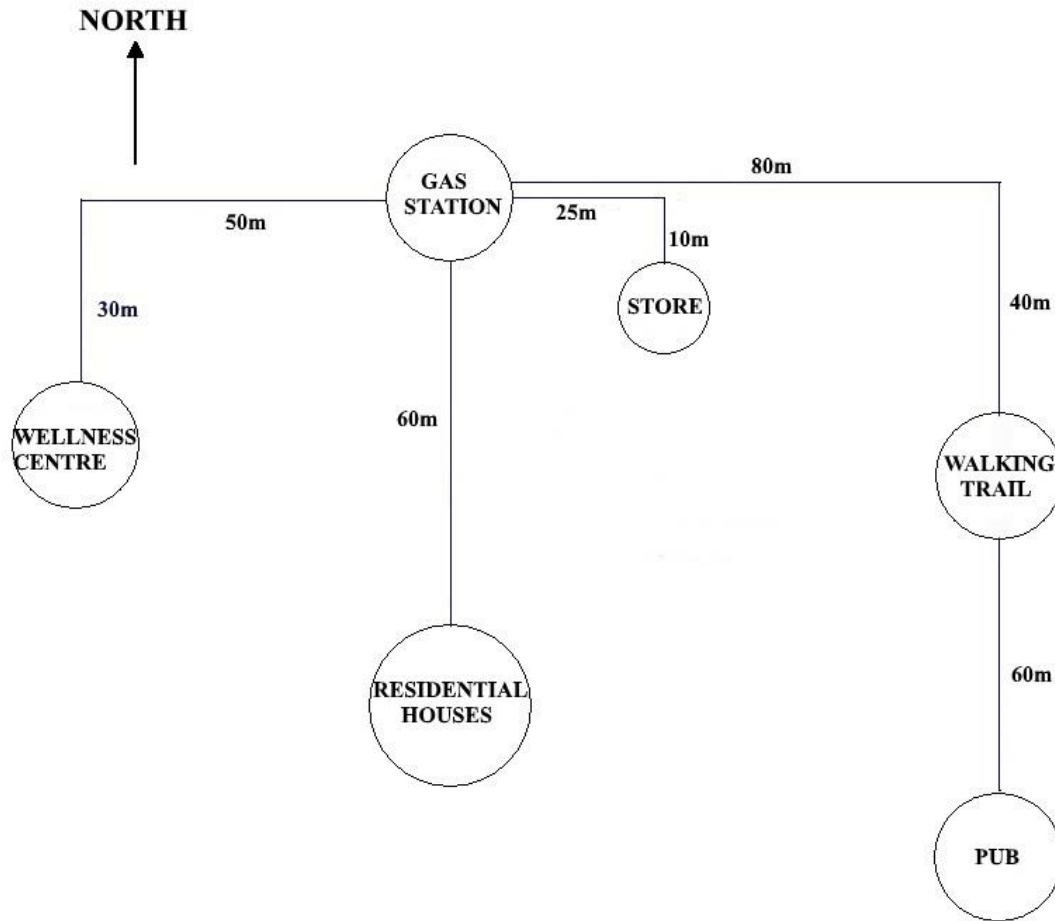
Figure 2-1: RBCA Process Flowchart (ASTM, 2015)

### **Chapter 3: Happy Valley – Goose Bay – Site Scenario**

This particular case study located in Happy Valley – Goose Bay, NL is entirely fabricated.

In Happy Valley – Goose Bay, NL, a gas station has been suspected of accidentally releasing total petroleum hydrocarbons (TPH) into the soil and groundwater after various complaints from nearby residents and employees were sent to the Happy Valley – Goose Bay Town Council. The Town Council hired local Environmental Engineering Company “Oil out of Soil Inc.” to provide an environmental assessment. The assessment results stated there were large quantities of TPH found in the soil and groundwater which were caused by a punctured underground storage tank. The exact release amount is unknown but verified at least five thousand litres of TPH has been released into the soil and groundwater and negatively affected the surrounding environment.

The report recommended the results be forwarded to the proper authorities and affected parties of the health and environmental risks found in the area (ASTM, 2015). They recommended implementing Risk Based Corrective Action (RBCA) and collection of soil and groundwater samples to calculate the TPH release. Figure 3-1 illustrates a general map of exposed areas of concern.



**Figure 3-1: General Map of Exposed Areas of Concern**

The Gas Station located in Happy Valley – Goose Bay is a commercial site with commercial receptors, it is mainly used in the town as a service to refuel motorized vehicles and equipment. The soil is composed of fine grained sand and the groundwater is a source of potable drinking water.

The Wellness Centre is a commercial site with commercial receptors and is mainly used for a variety of healthcare therapy services. The soil is composed of fine grained sand and the groundwater is a source of potable drinking water.

The Store is a commercial site with commercial receptors and is mainly used for purchasing of general items such as food and other convenient supplies. The soil is composed of fine grained sand and the groundwater is a source of potable drinking water.

The Residential Houses are a residential site with residential receptors and are mainly used as homes for people. The soil is composed of fine grained sand and the groundwater is a source of potable drinking water.

The Walking Trail is a residential site with residential receptors and is mainly used for leisure activities for the public such as walking, biking, picnics etc. The soil is composed of fine grained sand and the groundwater is a source of potable drinking water.

The Pub is commercial site with commercial receptors and is mainly used as a restaurant, lounge and entertainment. The soil is composed of fine grained sand and the groundwater is a source of potable drinking water.

It was determined that Happy-Valley-Goose Bay which is located in Labrador has a terrain composed of fine grained sand with silt layers. (NEIA, 2008) It has a 40 metre deep aquifer that is unconfined, unconsolidated high permeable fine grained sand with a minor horizontal anisotropy. (NEIA, 2008)

The town of Happy Valley – Goose Bay has a groundwater flow that is directly southeast and is 5 metres below ground surface with an average seasonal velocity of 5475 centimetres per year. (NEIA, 2008) The soil profile of this town is composed of recent alluvium with a thickness of 5 metres, terrace deposits of sand and silt with a thickness of

10 metres, till with a thickness of 10 metres and the lower alluvium with a thickness of 15 metres. (NEIA, 2008)

Soil and groundwater samples from each of the nearby sites that are of concern to exposure to the TPH release were collected. This process involved collecting five soil and five groundwater samples from various locations around the Gas Station labelled: GS-1, GS-2, GS-3, GS-4 and GS-5.

Three soil and three groundwater samples were taken from the Wellness Centre labelled: WC-1, WC-2 and WC-3.

Three soil and three groundwater samples were taken from the Store labelled: S-1, S-2 and S-3.

Three soil and three groundwater samples were taken from the Residential Site labelled: RH-1, RH-2 and RH-3.

Three soil and three groundwater samples were taken from the Walking Trail labelled: WT-1, WT-2 and WT-3.

Finally, three soil and three groundwater samples were taken from the Pub labelled: P-1, P-2, and P-3.

Soil samples were collected by drilling boreholes at various depths from the ground surface to the groundwater using a truck-mounted drilling rig which is equipped with a split spoon drilling system combined with solid stem augers. (EXP, 2017) All of these specific site data for soil is collected at regular intervals in the borehole by use of a

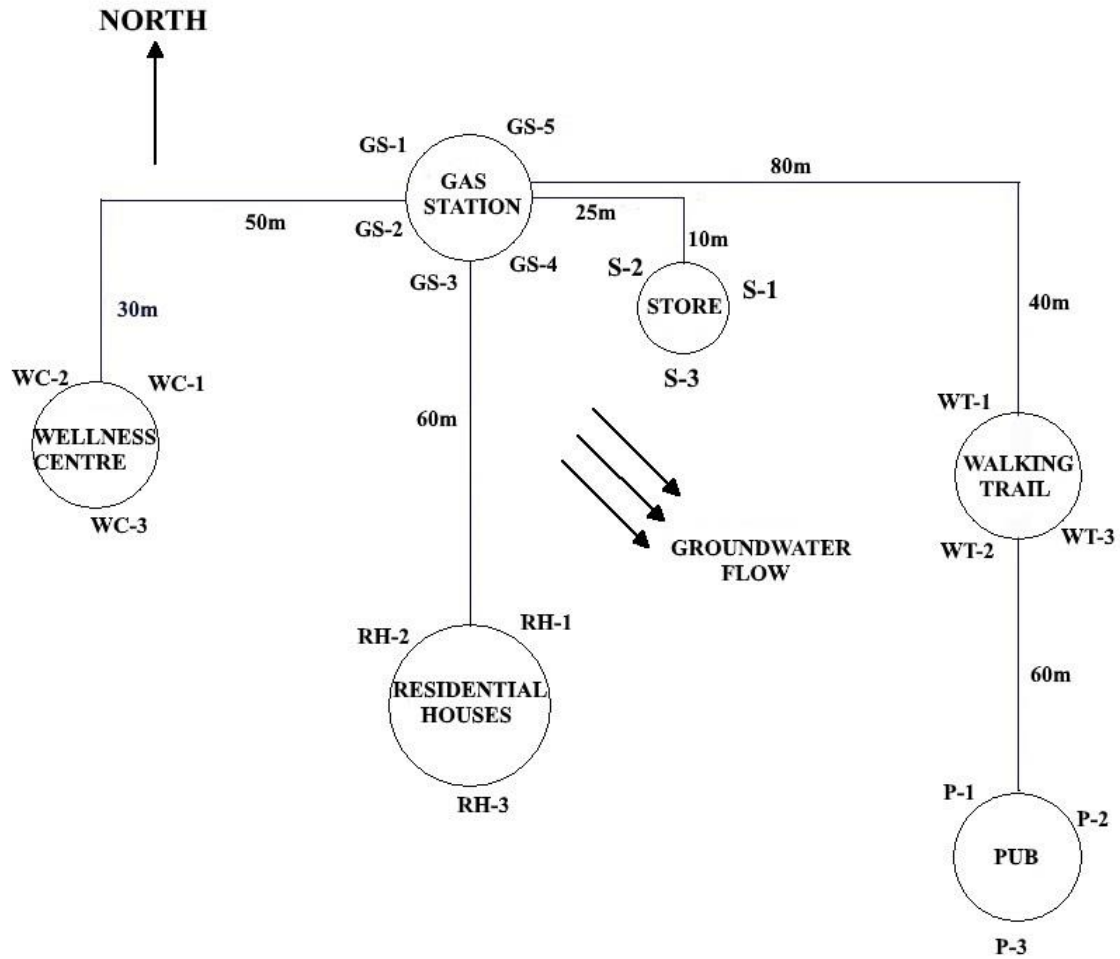
stainless steel split spoon samplers which are sterile and cleaned after each use. (EXP, 2017)

Groundwater samples were collected by installing groundwater monitoring wells from the drilled boreholes which are composed of a 50 millimeter diameter PVC screen with an overall length to the groundwater. (EXP, 2017) The annular space gap around the monitoring well was backfilled with sand then sealed with bentonite and completed with a protective casing. (EXP, 2017) Monitoring wells can aid in accurate measuring of the groundwater flow and direction. (EXP, 2017)

The soil and groundwater samples are then stored in approved sterile containers (EXP, 2017) and transported to a local laboratory called “E-Z Labs” who then measured the concentration levels of each soil and groundwater samples which were measured using various laboratory testing equipment to aid in the monitoring of residential and commercial receptors exposure to contamination, risk of contamination, and the need for remediation. (Cassen, 2020)

All the collected approximate soil and groundwater sample locations with groundwater direction flow is illustrated in Figure 3-2.





**Figure 3-2: Location of Soil and Groundwater Samples with Labels**

The soil and groundwater laboratory results for each of the locations: Gas Station, Wellness Centre, Store, Residential Houses, Walking Trail and Pub are located in the following Tables 3-1 to 3-6. The soil and groundwater samples results represent the maximum concentrations found in each specific sample location.

**Table 3-1: Gas Station - Soil and Groundwater Laboratory Results**

Location: Gas Station			
Commercial Site			
Fine Grained Sand & Potable Water			
Sample Name	Chemical of Concern	Soil Concentration (mg/kg)	Groundwater Concentration (mg/L)
GS-1	Benzene	600	5.9
	Toluene	640	5.2
	Ethylbenzene	500	4.8
	Xylene	600	4.2
GS-2	Benzene	550	4.8
	Toluene	610	4.7
	Ethylbenzene	600	5.3
	Xylene	710	4.5
GS-3	Benzene	570	5.2
	Toluene	575	4.2
	Ethylbenzene	550	4.1
	Xylene	640	3.9
GS-4	Benzene	500	4.1
	Toluene	560	5.1
	Ethylbenzene	590	4.5
	Xylene	590	3.8
GS-5	Benzene	520	4.4
	Toluene	580	4.7
	Ethylbenzene	480	4.3
	Xylene	570	3.5

**Table 3-2: Wellness Centre - Soil and Groundwater Laboratory Results**

Location: Wellness Centre			
Commercial Site			
Fine Grained Sand & Potable Water			
Sample Name	Chemical of Concern	Soil Concentration (mg/kg)	Groundwater Concentration (mg/L)
WC-1	Benzene	0.082	0.036
	Toluene	0.096	0.044
	Ethylbenzene	0.086	0.038
	Xylene	0.099	0.032
WC-2	Benzene	0.075	0.034
	Toluene	0.086	0.041
	Ethylbenzene	0.082	0.04
	Xylene	0.091	0.034
WC-3	Benzene	0.079	0.031
	Toluene	0.095	0.038
	Ethylbenzene	0.078	0.036
	Xylene	0.095	0.035

**Table 3-3: Store - Soil and Groundwater Laboratory Results**

Location: Store			
Commercial Site			
Fine Grained Sand & Potable Water			
Sample Name	Chemical of Concern	Soil Concentration (mg/kg)	Groundwater Concentration (mg/L)
S-1	Benzene	6	0.72
	Toluene	7.5	0.55
	Ethylbenzene	5.5	0.59
	Xylene	5.9	0.66
S-2	Benzene	5.9	0.88
	Toluene	5.1	0.66
	Ethylbenzene	6.5	0.62
	Xylene	4.8	0.57
S-3	Benzene	5.1	0.78
	Toluene	6	0.75
	Ethylbenzene	4.7	0.59
	Xylene	4.4	0.63

**Table 3-4: Residential Houses - Soil and Groundwater Laboratory Results**

Location: Residential Houses			
Residential Site			
Fine Grained Sand & Potable Water			
Sample Name	Chemical of Concern	Soil Concentration (mg/kg)	Groundwater Concentration (mg/L)
RH-1	Benzene	0.22	0.022
	Toluene	0.31	0.036
	Ethylbenzene	0.21	0.017
	Xylene	0.38	0.041
RH-2	Benzene	0.23	0.032
	Toluene	0.36	0.028
	Ethylbenzene	0.36	0.019
	Xylene	0.48	0.035
RH-3	Benzene	0.25	0.039
	Toluene	0.341	0.051
	Ethylbenzene	0.254	0.033
	Xylene	0.333	0.028

**Table 3-5: Walking Trail - Soil and Groundwater Laboratory Results**

Location: Walking Trail			
Residential Site			
Fine Grained Sand & Potable Water			
Sample Name	Chemical of Concern	Soil Concentration (mg/kg)	Groundwater Concentration (mg/L)
WT-1	Benzene	0.9	0.12
	Toluene	0.86	0.23
	Ethylbenzene	0.7	0.32
	Xylene	0.98	0.21
WT-2	Benzene	0.92	0.15
	Toluene	0.85	0.24
	Ethylbenzene	0.68	0.23
	Xylene	0.88	0.302
WT-3	Benzene	0.88	0.22
	Toluene	0.812	0.223
	Ethylbenzene	0.693	0.352
	Xylene	0.896	0.28

**Table 3-6: Pub - Soil and Groundwater Laboratory Results**

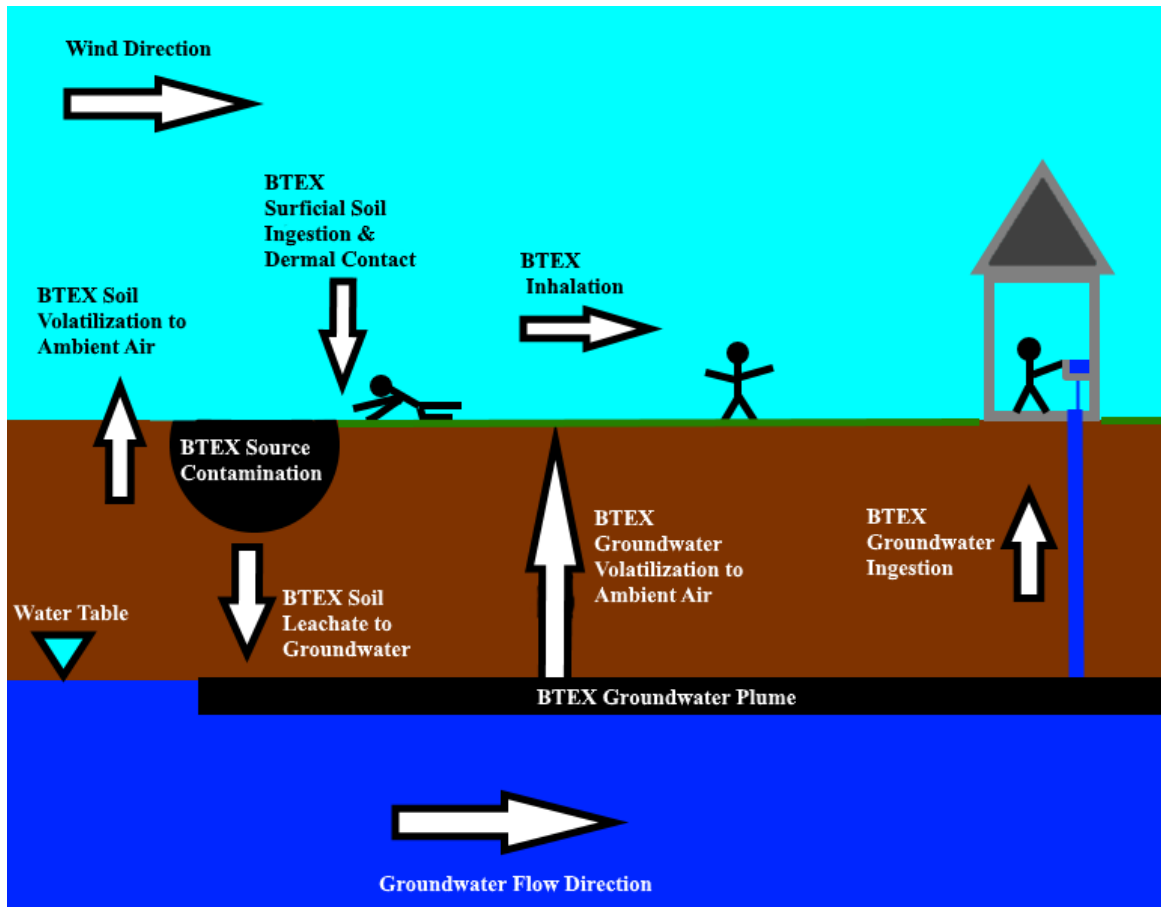
Location: Pub			
Commercial Site			
Fine Grained Sand & Potable Water			
Sample Name	Chemical of Concern	Soil Concentration (mg/kg)	Groundwater Concentration (mg/L)
P-1	Benzene	0.048	0.012
	Toluene	0.125	0.013
	Ethylbenzene	0.066	0.026
	Xylene	0.22	0.014
P-2	Benzene	0.031	0.011
	Toluene	0.21	0.015
	Ethylbenzene	0.077	0.022
	Xylene	0.32	0.018
P-3	Benzene	0.046	0.013
	Toluene	0.19	0.018
	Ethylbenzene	0.053	0.012
	Xylene	0.36	0.026

“Oil out of Soil Inc.” analyzed the soil and groundwater laboratory results in Tables 3-1 to 3-6 from “E-Z-Labs” to identify the chemicals of concern from the constituents of TPH. They discovered the main chemicals of concern in the TPH release were: Benzene, Toluene, Ethylbenzene, and mixed Xylenes. These chemicals of concern are usually referred to as BTEX and are known to have acute and chronic health effects. (ATSDR, 1999)

The major source and maximum concentrations of the BTEX contamination were located at the Gas Station. Also, at the Wellness Centre, Store, Residential Houses, Walking Trail and Pub, they noticed that the BTEX has indeed impacted these sites soil and groundwater in various concentration levels.

Each constitute of BTEX have similar potential significant transport and exposure pathways. (ATSDR, 1999) The following figure 3-3 and 3-4 show a conceptual site model and exposure scenario evaluation flowchart to illustrate a visual guide for BTEX transportation and to select the proper exposure scenarios.





**Figure 3-3: Conceptual Site Model**

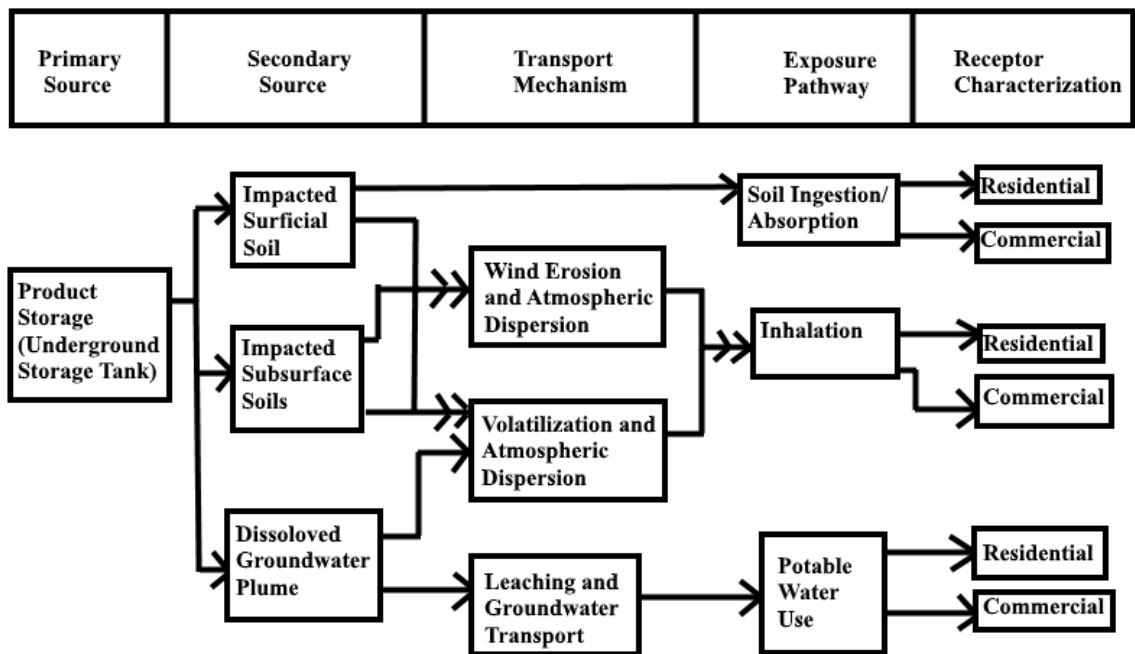


Figure 3-4: Exposure Scenario Evaluation Flowchart (ASTM, 2015)

## Chapter 4: Site Classification and Initial Response Plan Priority Criteria

There are four different site classification priority criteria combined with respective initial response actions for each scenario example. The priority criteria are integrated with a number value ranking of 1, 2, 3, and 4 from highest threat to lowest threat. A scenario with a priority number of 1 will have the highest ranked threat to human health, safety, or environment, while a scenario with a priority number of 4 will have the lowest ranked threat. (ASTM, 2015)

Tables 4-1 to 4-4 show the potential scenario(s) and potential initial response plan(s) for each of the four priority numbers for a BTEX contaminated site which are relative guidelines suggested by the ASTM, where each criterion must notify appropriate authorities, property owners, and potentially affected parties. (ASTM, 2015)

1. Immediate threat to human health, safety, or sensitive environmental receptors.

**Table 4-1: Priority 1 Scenario and Initial Response Plan (ASTM, 2015)**

Potential Scenario	Potential Initial Response Plan
BTEX has impacted or immediately contaminated an active public potable water supply well, line, or intake	Notify all potential impacted users, provide alternative potable water supply, and/or treat water at usage point.
BTEX free-product is found in large quantities on ground surface, surface water runoff, or surface water bodies.	Restrict access to the contaminated area, prevent further free-product transportation, and/or apply free-product recovery methods.
Ambient BTEX vapour concentrations surpass the BTEX levels from a safety point of view.	Restrict access to the contaminated area and/or remove source.
BTEX vapour concentrations in a building are at explosive levels or can cause acute health issues.	Evacuate occupants and begin BTEX abatement.
BTEX is directly affecting a sensitive environmental habitat or resource.	Minimize exposure by implementation of habitat management.

Table 4-1 illustrates a scenario and initial response plan to priority number 1 criteria which is an immediate threat to human health, safety, or sensitive environmental receptors. (ASTM, 2015)

Priority number 1 is the highest ranked threat and for each potential scenario of BTEX contamination then the necessary initial response plan(s) should be implemented immediately as the contamination is currently negatively affecting the surrounding environment. (ASTM, 2015)

2. Short-term (0-2 years) threat to human health, safety, or sensitive environmental receptors.

**Table 4-2: Priority 2 Scenario and Initial Response Plan (ASTM, 2015)**

Potential Scenario	Potential Initial Response Plan
Potential for BTEX vapours to accumulate in building to explosive levels or cause acute health effects.	Remove source and/or assess vapour migration pathways.
BTEX contamination in surficial soil is open to public or residential access within 152m to contamination.	Restrict access to public areas, remove or cover soils.
A non-potable water supply has been contaminated by BTEX.	Notify users, use alternate water supply, and/or treat water at usage point.
There is potential for BTEX to contaminate a potable drinking water source or future water source.	Monitor groundwater quality and/or prevent vertical migration of BTEX.
Sensitive environmental habitat or resource is located within 152m of BTEX contamination.	Implement containment procedures, restrict access, and evaluate magnitude of potential harmful effects.

Table 4-2 illustrates a scenario and initial response plan to priority number 2 criteria which is a short-term threat to human health, safety, or sensitive environmental receptors. (ASTM, 2015)

Priority number 2 is the second highest ranked threat and for each potential scenario of BTEX contamination then the necessary initial response plan(s) should be commenced as soon as possible to mitigate the short term threat to prevent any hazardous environmental conditions in 0-2 years.. (ASTM, 2015)

3. Long-term (2+ years) threat to human health, safety, or sensitive environmental receptors.

**Table 4-3: Priority 3 Scenario and Initial Response Plan (ASTM, 2015)**

Potential Scenario	Potential Initial Response Plan
BTEX concentration is significant in subsurface soils and potable aquifer is 15m from contamination.	Monitor groundwater and determine BTEX mitigation to the aquifer.
Groundwater is impacted by BTEX and threatens a potable water source in 2+ years.	Monitor BTEX groundwater plume and evaluate potential for natural attenuation.
BTEX is impacting shallow surficial soils that are open to the public and are within 152m of contamination.	Restrict access to contaminated area,
BTEX surface runoff or groundwater discharge is within 457m of a sensitive habitat or potable water source.	Evaluate impact of sensitive area contamination and restrict access to areas of discharge.

Table 4-3 illustrates a scenario and initial response plan to priority number 3 criteria which is a long-term threat to human health, safety, or sensitive environmental receptors. (ASTM, 2015)

Priority number 3 is the third highest ranked threat and for each potential scenario of BTEX contamination then the necessary initial response plan(s) should be commenced as soon as possible to mitigate the long term threat to prevent any hazardous environmental conditions in 2+ years. (ASTM, 2015)

4. No demonstrable long-term threat to human, safety, or sensitive environmental receptors.

**Table 4-4: Priority 4 Scenario and Initial Response Plan (ASTM, 2015)**

Potential Scenario	Potential Initial Response Plan
BTEX impacted a non-potable water source that has no local use.	Monitor groundwater and evaluate for natural attenuation.
Impacted BTEX soils are more than 0.9m below ground surface and 15m above nearest aquifer.	Monitor groundwater and evaluate natural attenuation.

Table 4-4 illustrates a scenario and initial response plan to priority number 4 criteria which has no demonstrable long-term threat to human health, safety, or sensitive environmental receptors. (ASTM, 2015)

Priority number 4 is the lowest ranked threat and for each potential scenario of BTEX contamination then the necessary initial response plan(s) should be commenced as soon as possible to ensure the area is monitored to prevent any hazardous threats to the environment. (ASTM, 2015)

## **Chapter 5: Tier 1**

### **5.1 Site Classification and Initial Response Plan**

In Tier 1, the site must be reclassified (ASTM, 2015) and from Site Classification and Initial Response Plan Priority Criteria from Chapter 4 that this particular case study in Happy Valley-Goose Bay is a priority number 1 case scenario which is the highest ranked threat. (ASTM, 2015)

It is a priority number 1 because from Table 4-1 located in Chapter 4 and from the contaminated Happy Valley – Goose Bay site that BTEX has impacted or immediately contaminated an active public potable water supply well, line, or intake and the ambient BTEX vapour concentrations surpass the BTEX levels from a safety point of view. (ASTM, 2015)

In this scenario the initial response plan is to notify authorities, property owners, and potentially affected parties about the adverse health and environmental risks in the area. (ASTM, 2015) In regards to the contaminated potable water and soil, there are potential initial response plans to provide alternative potable water supply and/or treat water at usage point, restrict access to the contaminated area and/or remove source of contamination. (ASTM, 2015)

Also, since this is a priority number 1 which is an immediate threat to human health, safety, or sensitive environmental receptors then each scenario of BTEX contamination should implement all necessary initial response plan(s) immediately as the contamination is currently negatively affecting the surrounding environment. (ASTM, 2015)

## 5.2 Tier 1 - Evaluation

In Tier 1 evaluation, risk based screening levels (RBSL) are calculated to develop a look-up table which is used to compare to the BTEX chemicals of concern concentration levels found in the soil and groundwater. (ASTM, 2015) Each of the potential exposure pathways has a RBSL calculated and developed for a commercial or residential receptor that can potentially be at risk to the harmful adverse effects of BTEX. (ASTM, 2015) The BTEX RBSL's in this case study include: soil volatilization to ambient air, surficial soil, soil leachate to groundwater, groundwater ingestion and groundwater volatilization to ambient air.

The formulation for the RBSL's pathways is presented in the following section with Tier 1 carcinogenic and non-carcinogenic RBSL's equations. (Husain, T.,2002)(ASTM, 2015)

### Tier 1 RBSL Carcinogenic Equations:

#### Air inhalation

#### Equation (1)

$$RBSL_{air} \left[ \frac{\mu g}{m^3 - air} \right] = \frac{TR \times BW \times AT_c \times 365 \frac{days}{year} \times 10^3 \frac{\mu g}{mg}}{SF_i \times IR_{air} \times EF \times ED}$$

Equation 1 calculates the RBSL for carcinogenic chemicals to represent the maximum allowable chemical concentration inhaled into the human body via contaminated air inhalation. (ASTM, 2015)



**Groundwater ingestion (potable water)****Equation (2)**

$$RBSL_w \left[ \frac{\text{mg}}{\text{L} - \text{H}_2\text{O}} \right] = \frac{TR \times BW \times AT_c \times 365 \frac{\text{days}}{\text{year}}}{SF_o \times IR_w \times EF \times ED}$$

Equation 2 calculates the RBSL for carcinogenic chemicals to represent the maximum allowable chemical concentration ingested into the human body via contaminated groundwater ingestion of potable drinking water. (ASTM, 2015)

**Groundwater ambient vapour inhalation****Equation (3)**

$$RBSL_w \left[ \frac{\text{mg}}{\text{L} - \text{H}_2\text{O}} \right] = \frac{RBSL_{air} \left[ \frac{\mu\text{g}}{\text{m}^3 - \text{air}} \right]}{VF_{wamb}} \times 10^{-3} \frac{\text{mg}}{\mu\text{g}}$$

Equation 3 calculates the RBSL for carcinogenic chemicals to represent the maximum allowable chemical concentration inhaled into the human body via contaminated air inhalation from chemical groundwater vapours that are directed towards the surface and into the ambient air. (ASTM, 2015)

**Surficial soil – ingestion of soil, inhalation of vapours and particulates, and dermal contact****Equation (4)**

$$RBSL_s \left[ \frac{\text{mg}}{\text{kg} - \text{soil}} \right] = \frac{TR \times BW \times AT_c \times 365 \frac{\text{days}}{\text{year}}}{EF \times ED \left[ \left( SF_o \times 10^{-6} \frac{\text{kg}}{\text{mg}} \times (IR_{soil} \times RAF_o + SA \times M \times RAF_d) \right) + (SF_i \times IR_{air} \times (VF_{ss} + VF_p)) \right]}$$

Equation 4 calculates the RBSL for carcinogenic chemicals to represent the maximum allowable chemical concentration ingested, inhaled and/or absorbed into the human body via contaminated surficial soil. (ASTM, 2015)

**Subsurface soil – ambient vapour inhalation**

**Equation (5)**

$$\text{RBSL}_s \left[ \frac{\text{mg}}{\text{kg} - \text{soil}} \right] = \frac{\text{RBSL}_{\text{air}} \left[ \frac{\mu\text{g}}{\text{m}^3 - \text{air}} \right]}{\text{VF}_{\text{samb}}} \times 10^{-3} \frac{\text{mg}}{\mu\text{g}}$$

Equation 5 calculates the RBSL for carcinogenic chemicals to represent the maximum allowable chemical concentration inhaled into the human body via contaminated subsurface soil vapours that are directed upwards to the surface and into the ambient air. (ASTM, 2015)

**Subsurface soil – leaching to groundwater**

**Equation (6)**

$$\text{RBSL}_s \left[ \frac{\text{mg}}{\text{kg} - \text{soil}} \right] = \frac{\text{RBSL}_w \left[ \frac{\text{mg}}{\text{L} - \text{H}_2\text{O}} \right]}{\text{LF}_{\text{sw}}}$$

Equation 6 calculates the RBSL for carcinogenic chemicals to represent the maximum allowable chemical concentration to leach into the groundwater from contaminated subsurface that can potentially contaminate a potable groundwater source. (ASTM, 2015)

## **Tier 1 RBSL's Non-Carcinogenic Equations:**

### **Air inhalation**

**Equation (7)**

$$\text{RBSL}_{\text{air}} \left[ \frac{\mu\text{g}}{\text{m}^3 - \text{air}} \right] = \frac{\text{THQ} \times \text{RfD}_i \times \text{BW} \times \text{AT}_n \times 365 \frac{\text{days}}{\text{year}} \times 10^3 \frac{\mu\text{g}}{\text{mg}}}{\text{IR}_{\text{air}} \times \text{EF} \times \text{ED}}$$

Equation 7 calculates the RBSL for non-carcinogenic chemicals to represent the maximum allowable chemical concentration inhaled into the human body via contaminated air inhalation. (ASTM, 2015)

### **Groundwater ingestion (potable water)**

**Equation (8)**

$$\text{RBSL}_w \left[ \frac{\text{mg}}{\text{L} - \text{H}_2\text{O}} \right] = \frac{\text{THQ} \times \text{RfD}_o \times \text{BW} \times \text{AT}_n \times 365 \frac{\text{days}}{\text{year}}}{\text{IR}_w \times \text{EF} \times \text{ED}}$$

Equation 8 calculates the RBSL for non-carcinogenic chemicals to represent the maximum allowable chemical concentration ingested into the human body via contaminated groundwater ingestion of potable drinking water. (ASTM, 2015)

### **Groundwater ambient (outdoor) vapour inhalation**

**Equation (9)**

$$\text{RBSL}_w \left[ \frac{\text{mg}}{\text{L} - \text{H}_2\text{O}} \right] = \frac{\text{RBSL}_{\text{air}} \left[ \frac{\mu\text{g}}{\text{m}^3 - \text{air}} \right]}{\text{VF}_{\text{wamb}}} \times 10^{-3} \frac{\text{mg}}{\mu\text{g}}$$

Equation 9 calculates the RBSL for non-carcinogenic chemicals to represent the maximum allowable chemical concentration inhaled into the human body via contaminated air inhalation from chemical groundwater vapours that are directed towards the surface and into the ambient air. (ASTM, 2015)

**Surficial soil ingestion of soil, inhalation of vapours and particulates, and dermal contact**

**Equation (10)**

$$\text{RBSL}_s \left[ \frac{\text{mg}}{\text{kg - soil}} \right] = \frac{\text{THQ} \times \text{BW} \times \text{AT}_n \times 365 \frac{\text{days}}{\text{year}}}{\text{EF} \times \text{ED} \left( \frac{10^{-6} \frac{\text{kg}}{\text{mg}} \times (\text{IR}_{\text{soil}} \times \text{RAF}_o + \text{SA} \times \text{M} \times \text{RAF}_d) \right)} + (\text{IR}_{\text{air}} \times (\text{VF}_{\text{ss}} + \text{VF}_p)) \text{RfD}_o$$

Equation 10 calculates the RBSL for non-carcinogenic chemicals to represent the maximum allowable chemical concentration inhaled into the human body via contaminated subsurface soil vapours that are directed upwards to the surface and into the ambient air. (ASTM, 2015)

**Subsurface soil ambient vapour inhalation**

**Equation (11)**

$$\text{RBSL}_s \left[ \frac{\text{mg}}{\text{kg - soil}} \right] = \frac{\text{RBSL}_{\text{air}} \left[ \frac{\mu\text{g}}{\text{m}^3 - \text{air}} \right]}{\text{VF}_{\text{samb}}} \times 10^{-3} \frac{\text{mg}}{\mu\text{g}}$$

Equation 11 calculates the RBSL for non-carcinogenic chemicals to represent the maximum allowable chemical concentration inhaled into the human body via contaminated subsurface soil vapours that are directed upwards to the surface and into the ambient air. (ASTM, 2015)

**Subsurface soil leaching to groundwater**

**(Equation 12)**

$$\text{RBSL}_s \left[ \frac{\text{mg}}{\text{kg - soil}} \right] = \frac{\text{RBSL}_w \left[ \frac{\text{mg}}{\text{L - H}_2\text{O}} \right]}{\text{LF}_{\text{sw}}}$$

Equation 12 calculates the RBSL for non-carcinogenic chemicals to represent the maximum allowable chemical concentration to leach into the groundwater from contaminated subsurface that can potentially contaminate a potable groundwater source. (ASTM, 2015)

### **Volatilization Factors:**

#### **Surficial soils to ambient air vapours**

**Equation (13)**

$$VF_{ss} \left[ \frac{(\text{mg}/\text{m}^3 - \text{air})}{(\text{mg}/\text{kg} - \text{soil})} \right] = \frac{2W\rho_s}{U_{\text{air}}\delta_{\text{air}}} \sqrt{\frac{D_{\text{eff}}^s H}{\pi[\theta_{ws} + k_s\rho_s + H\theta_{as}]}} \tau \times 10^3 \frac{\text{cm}^3 - \text{kg}}{\text{m}^3 - \text{g}}$$

**or:**

**Equation (14)**

$$VF_{ss} \left[ \frac{(\text{mg}/\text{m}^3 - \text{air})}{(\text{mg}/\text{kg} - \text{soil})} \right] = \frac{W\rho_s d}{U_{\text{air}}\delta_{\text{air}}\tau} \times 10^3 \frac{\text{cm}^3 - \text{kg}}{\text{m}^3 - \text{g}}$$

**\* whichever is less**

Equations 13 and 14 calculate the volatilization factor for surficial soils to ambient air vapours which are necessary to calculate the RBSL for surficial soil ingestion of soil, inhalation of vapours and particulates, and dermal contact in Equations 4 and 10.

Whichever value is less, then that value is selected in RBSL calculations. (ASTM, 2015)

#### **Surficial soils – ambient air particles**

**Equation (15)**

$$VF_p \left[ \frac{(\text{mg}/\text{m}^3 - \text{air})}{(\text{mg}/\text{kg} - \text{soil})} \right] = \frac{P_e W}{U_{\text{air}}\delta_{\text{air}}} \times 10^3 \frac{\text{cm}^3 - \text{kg}}{\text{m}^3 - \text{g}}$$

Equation 15 calculates the volatilization factor for surficial soils to ambient air particles which is necessary to calculate the RBSL for surficial soil ingestion of soil, inhalation of vapours and particulates, and dermal contact in Equations 4 and 10. (ASTM, 2015)

**Subsurface soils – Ambient Air**

**Equation (16)**

$$VF_{samb} \left[ \frac{(\text{mg}/\text{m}^3 - \text{air})}{(\text{mg}/\text{kg} - \text{soil})} \right] = \frac{H\rho_s}{[\theta_{ws} + k_s\rho_s + H\theta_{as}] \times \left( 1 + \frac{U_{air} \delta_{air} L_s}{D_{eff}^s W} \right)} \times 10^3 \frac{\text{cm}^3 - \text{kg}}{\text{m}^3 - \text{g}}$$

Equation 16 calculates the volatilization factor for subsurface soils to ambient air which is necessary to calculate the RBSL for subsurface soil – ambient vapour inhalation in Equations 5 and 11. (ASTM, 2015)

**Leaching factor - subsurface soils – groundwater**

**Equation (17)**

$$LF_{sw} \left[ \frac{(\text{mg}/\text{L} - \text{H}_2\text{O})}{(\text{mg}/\text{kg} - \text{soil})} \right] = \frac{\rho_s}{[\theta_{ws} + k_s\rho_s + H\theta_{as}] \times \left( 1 + \frac{U_{gw} \delta_{gw} L_s}{IW} \right)} \times 10^0 \frac{\text{cm}^3 - \text{kg}}{\text{L} - \text{g}}$$

Equation 17 calculates the leaching factor from subsurface soils to the groundwater which is necessary to calculate the RBSL for subsurface soil leaching to groundwater in Equations 6 and 12.

**Effective Diffusion coefficient in soil**

**Equation (18)**

$$D_{eff}^s \left[ \frac{\text{cm}^2}{\text{s}} \right] = D^{air} \frac{\theta_{as}^{3.33}}{\theta_T^2} + D^{wat} \frac{1}{H} \frac{\theta_{ws}^{3.33}}{\theta_T^2}$$

Equation 18 calculates the effective diffusion coefficient in soil which is necessary in many equations to represent contaminant transport through the soil and vadose zone.

(ASTM, 2015)

In Equations 1 to 18, each parameter is defined in the following Tables 5-1 and 5-2 along with its ASTM Tier 1 default residential, commercial and chemical specific values. These default parameters are based off ASTM standards for Tier 1 evaluation and site specific data is not necessary at this stage of RBCA. The target excess individual lifetime cancer risk and target quotient are 1.00E-06 (one in a million) and 1.00 respectively for this particular case study in Happy Valley-Goose Bay.

In Tables 5-1 and 5-2 there is a residential and commercial receptor parameter data where residential receptors may have higher data or equal data as a commercial receptor.

Residential receptors will have certain parameters values that are higher than a commercial receptor because a residential receptor will generally on average inhale, ingest, and absorb a higher dosage of contaminants since they are on site and exposed for longer duration than a commercial receptor. (ASTM, 2015) Other values will have the same parameter value as they are not dependent on exposure duration such as average adult body weight, soil to skin adherence factor, site and chemical specific values, etc. (ASTM, 2015) Whereas, exposure dependent factors such as daily water ingestion rate, soil ingestion rate, and average time for vapour flux, etc. are dependent on how long a receptor is exposed to contamination while on site. (ASTM, 2015)

All data in Table 5-1 and Table 5-2 is referenced from ASTM. ASTM has developed each parameter value based off various research studies to generate acceptable data for Tier 1 evaluations. (ASTM, 2015)

**Table 5-1: Tier 1 - RBSL Default Exposure Parameters (ASTM, 2015)**

Tier 1 - RBSL Default Exposure Parameters			
Parameter	Definition (Units)	Residential	Commercial
AT <sub>c</sub>	averaging time for carcinogens (years)	70	70
AT <sub>n</sub>	averaging time for noncarcinogens (years)	30	25
BW	adult body weight (kg)	70	70
ED	exposure duration (years)	30	25
EF	exposure frequency (days/year)	350	250
IR <sub>soil</sub>	soil ingestion rate (mg/day)	100	50
IR <sub>air</sub>	daily outdoor inhalation rate (m <sup>3</sup> /day)	20	20
IR <sub>w</sub>	daily water ingestion rate (L/day)	2	1
M	soil to skin adherence factor (mg/cm <sup>2</sup> )	0.5	0.5
RAF <sub>d</sub> - Benzene	dermal relative absorption factor - PAH's (unitless)	0.05	0.05
RAF <sub>o</sub> - Benzene	oral relative absorption factor (unitless)	1	1
RfD <sub>i</sub> - Toluene	inhalation chronic reference dose (mg/kg-day)	0.2	0.2
RfDo - Toluene	oral chronic reference dose (mg/kg-day)	0.11	0.11
RfD <sub>i</sub> - Ethylbenzene	inhalation chronic reference dose (mg/kg-day)	0.029	0.029
RfDo - Ethylbenzene	oral chronic reference dose (mg/kg-day)	0.1	0.1
RfD <sub>i</sub> - Xylene	inhalation chronic reference dose (mg/kg-day)	0.09	0.09
RfD <sub>o</sub> - Xylene	oral chronic reference dose (mg/kg-day)	2	2
SA	skin surface area (cm <sup>2</sup> /day)	3160	3160
SF <sub>i</sub> - Benzene	inhalation cancer slope factor (kg-day/mg)	0.029	0.029
SF <sub>o</sub> - Benzene	oral cancer slope factor (kg-day/mg)	0.029	0.029
THQ	target hazard quotient (unitless)	1	1
TR	target excess individual lifetime cancer risk (unitless)	1.00E-06	1.00E-06



**Table 5-2: Tier 1 - RBSL Default Soil, Building, Surface and Subsurface Parameters  
(ASTM, 2015)**

Tier 1 - RBSL Default Soil, Building, Surface and Subsurface Parameters			
Parameter	Definition (Units)	Residential	Commercial
d	lower depth of surficial soil zone (cm)	100	100
D <sup>air</sup> - Benzene	diffusion coefficient in air (cm <sup>2</sup> /sec)	0.093	0.093
D <sup>wat</sup> - Benzene	diffusion coefficient in water (cm <sup>2</sup> /sec)	1.10E-05	1.10E-05
f <sub>oc</sub>	fraction of organic carbon in soil (g-C/g-soil)	0.01	0.01
H - Benzene	henry's law constant (cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air)	0.228	0.228
H -Toluene	henry's law constant (cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air)	0.272	0.272
H -Ethylbenzene	henry's law constant (cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air)	0.32	0.32
H -Xylene	henry's law constant (cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air)	0.29	0.29
h <sub>cap</sub>	thickness of capillary fringe (cm)	5	5
h <sub>v</sub>	thickness of vadose zone (cm)	295	295
I	infiltration rate of water through soil (cm/year)	30	30
logk <sub>oc</sub> - Benzene	carbon-water sorption coefficient (cm <sup>3</sup> -H <sub>2</sub> O/g - C)	1.58	1.58
logk <sub>oc</sub> - Toluene	carbon-water sorption coefficient (cm <sup>3</sup> -H <sub>2</sub> O/g - C)	2.13	2.13
logk <sub>oc</sub> - Ethylbenzene	carbon-water sorption coefficient (cm <sup>3</sup> -H <sub>2</sub> O/g - C)	3.11	3.11
logk <sub>oc</sub> - Xylene	carbon-water sorption coefficient (cm <sup>3</sup> -H <sub>2</sub> O/g - C)	2.38	2.38
k <sub>s</sub> - Benzene	soil-water sorption coefficient, k <sub>s</sub> =f <sub>oc</sub> k <sub>oc</sub> (cm <sup>3</sup> -H <sub>2</sub> O/g -soil)	0.38	0.38
k <sub>s</sub> - Toluene	soil-water sorption coefficient, k <sub>s</sub> =f <sub>oc</sub> k <sub>oc</sub> (cm <sup>3</sup> -H <sub>2</sub> O/g -soil)	1.35	1.35
k <sub>s</sub> - Ethylbenzene	soil-water sorption coefficient, k <sub>s</sub> =f <sub>oc</sub> k <sub>oc</sub> (cm <sup>3</sup> -H <sub>2</sub> O/g -soil)	12.88	12.88
k <sub>s</sub> - Xylene	soil-water sorption coefficient, k <sub>s</sub> =f <sub>oc</sub> k <sub>oc</sub> (cm <sup>3</sup> -H <sub>2</sub> O/g -soil)	2.4	2.4
L <sub>GW</sub>	depth to groundwater = h <sub>v</sub> +h <sub>cap</sub> (cm)	300	300
L <sub>S</sub>	depth to subsurface soils (cm)	100	100
P <sub>e</sub>	particulate emission rate (g/cm <sup>2</sup> -s)	6.90E-14	6.90E-14
U <sub>air</sub>	wind speed above ground surface (cm/s)	225	225
U <sub>gw</sub>	groundwater Darcy velocity (cm/year)	2500	2500
W	width of source area parallel to flow (cm)	1500	1500
δ <sub>air</sub>	ambient air mixing zone height (cm)	200	200
δ <sub>gw</sub>	groundwater mixing zone thickness (cm)	200	200
θ <sub>as</sub>	volumetric air content in vadose zone (cm <sup>3</sup> /cm <sup>3</sup> -soil)	0.26	0.26
θ <sub>T</sub>	total soil porosity (cm <sup>3</sup> /cm <sup>3</sup> -soil)	0.38	0.38
θ <sub>ws</sub>	volumetric water content in vadose zone (cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil)	0.12	0.12
ρ	soil bulk density (g/cm <sup>3</sup> )	1.7	1.7
τ	averaging time for vapor flux (sec)	9.46E+08	7.88E+08

For example, to calculate the RBSL for ingestion of benzene in potable groundwater for a commercial receptor, Equation 2 for groundwater ingestion (potable water) is used since benzene is a known carcinogenic chemical. From table 5-1, the commercial parameters are:  $TR=1.00E-06$ ,  $BW=70$  kg,  $AT_c=70$  years,  $SF_o=0.029$  kg-day/mg,  $IR_w=1L$ ,  $EF=250$  days, and  $ED = 25$  years. Entering these values into Equation 2, the RBSL for groundwater ingestion of benzene for a commercial receptor is 0.00987 mg/L.

Each calculated RBSL value is entered into the Tier 1 look-up table which is compared to the soil and groundwater laboratory samples located in Tables 3-1 to 3-6. (ASTM, 2015) If the site sample concentration exceeds the RBSL then Tier 2 is implemented or if it is lower than no further action is required as the concentration is below the threshold to cause adverse health and environmental effects. (ASTM, 2015)

The completed Tier 1 RBSL residential and commercial look-up tables are shown in the following Tables 5-3 and 5-4.

**Table 5-3: Tier 1 –RBSL Look-up Table for Residential Sites**

Tier 1 - RBSL Look-up Table					
Residential Sites					
Cancer Target Risk (TR) = 1E-06 , Chronic Hazard Quotient (HQ) =1					
Chemical of Concern	RBSL - Soil Volatilization to Ambient Air (mg/kg)	RBSL - Surficial Soil (mg/kg)	RBSL - Soil Leachate to Groundwater (mg/kg)	RBSL - Groundwater Ingestion (mg/L)	RBSL - Groundwater Volatilization to Ambient Air (mg/L)
Benzene	0.272	5.82	0.0172	0.00294	11
Toluene	RES	13300	129	7.3	>S
Ethylbenzene	RES	7830	575	3.65	>S
Xylene	RES	1450000	RES	73	>S
RES - Selected risk level is not exceeded for pure compound present at any concentration					
>S - Selected risk level is not exceeded for all possible dissolved levels					

**Table 5-4: Tier 1 –RBSL Look-up Table for Commercial Sites**

Tier 1 - RBSL Look-up Table					
Commercial Sites					
Cancer Target Risk (TR) = 1E-06 , Chronic Hazard Quotient (HQ) =1					
Chemical of Concern	RBSL - Soil Volatilization to Ambient Air (mg/kg)	RBSL - Surficial Soil (mg/kg)	RBSL - Soil Leachate to Groundwater (mg/kg)	RBSL - Groundwater Ingestion (mg/L)	RBSL - Groundwater Volatilization to Ambient Air (mg/L)
Benzene	0.457	10	0.0578	0.00987	18.4
Toluene	RES	18700	361	20.4	>S
Ethylbenzene	RES	11500	1610	10.2	>S
Xylene	RES	208000	RES	>S	>S
RES - Selected risk level is not exceeded for pure compound present at any concentration					
>S - Selected risk level is not exceeded for all possible dissolved levels					

### **5.3 Tier 1 – Results**

#### **Tier 1 - Gas Station Results**

After comparing the Gas Station's soil and groundwater BTEX concentration data to the Tier 1 RBSL look-up tables, the following Tier 1 RBSL's are exceeded:

- Soil volatilization to ambient air for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the RBSL of 0.457 mg/kg.
- Surficial soil for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the RBSL of 10 mg/kg.
- Soil leachate to groundwater for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the RBSL of 0.0578 mg/kg.
- Soil leachate to groundwater for toluene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the RBSL of 361 mg/kg.
- Groundwater ingestion for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 groundwater samples exceed the RBSL of 0.00987 mg/L.

### **Tier 1 - Wellness Centre Results**

After comparing the Wellness Centre's soil and groundwater BTEX concentration data to the Tier 1 RBSL look-up tables, the following commercial Tier 1 RBSL's are exceeded:

- Soil leachate to groundwater for benzene in the WC-1, WC-2, and WC-3 soil samples exceed the RBSL of 0.0578 mg/kg.
- Groundwater ingestion for benzene in the WC-1, WC-2, and WC-3 groundwater samples exceed the RBSL of 0.00987 mg/L.

### **Tier 1 - Store Results**

After comparing the Store's soil and groundwater BTEX concentration data to the Tier 1 RBSL look-up tables, the following commercial Tier 1 RBSL's are exceeded:

- Soil volatilization to ambient air for benzene in the S-1, S-2, and S-3 soil samples exceed the RBSL of 0.457 mg/kg.
- Soil leachate to groundwater for benzene in the S-1, S-2, and S-3 soil samples exceed the RBSL of 0.0578 mg/kg.
- Groundwater ingestion for benzene in the S-1, S-2, and S-3 groundwater samples exceed the RBSL of 0.00987 mg/L.

### **Tier 1 - Residential Houses Results**

After comparing the Residential Houses soil and groundwater BTEX concentration data to the Tier 1 RBSL look-up tables, the following residential Tier 1 RBSL's are exceeded:

- Soil leachate to groundwater for benzene in the RH-1, RH-2, and RH-3 soil samples exceed the RBSL of 0.0172 mg/kg.
- Groundwater ingestion for benzene in the RH-1, RH-2, and RH-3 groundwater samples exceed the RBSL of 0.00294 mg/L.

### **Tier 1 - Walking Trail Results**

After comparing the Walking Trail's soil and groundwater BTEX concentration data to the Tier 1 RBSL look-up tables, the following residential Tier 1 RBSL's are exceeded:

- Soil volatilization to ambient air for benzene in the WT-1, WT-2, and WT-3 soil samples exceed the RBSL of 0.272 mg/kg.
- Soil leachate to groundwater for benzene in the WT-1, WT-2, and WT-3 soil samples exceed the RBSL of 0.0172 mg/kg.
- Groundwater ingestion for benzene in the WT-1, WT-2, and WT-3 groundwater samples exceed the RBSL of 0.00294 mg/L.

### **Tier 1 - Pub Results**

After comparing the Pub's soil and groundwater BTEX concentration data to the Tier 1 RBSL look-up tables, the following commercial Tier 1 RBSL's are exceeded:

- Groundwater ingestion for benzene in the P-1, P-2, and P-3 groundwater samples exceed the RBSL of 0.00987 mg/L.

## **Chapter 6: Tier 2**

### **6.1 Site Classification and Initial Response Plan**

In Tier 2, the site requires reclassification (ASTM, 2015) and from Site Classification and Initial Response Plan Priority Criteria from Chapter 4 that this particular case study in Happy Valley-Goose Bay is a priority number 1 case scenario which is the highest ranked threat. (ASTM, 2015)

It is a priority number 1 because from Table 4-1 located in Chapter 4 and from the contaminated Happy Valley – Goose Bay site that BTEX has impacted or immediately contaminated an active public potable water supply well, line, or intake and the ambient BTEX vapour concentrations surpass the BTEX levels from a safety point of view with respect to Tier 1 RBSL's. (ASTM, 2015)

In this scenario the initial response plan is to notify authorities, property owners, and potentially affected parties about the adverse health and environmental risks in the area. (ASTM, 2015) In regards to the contaminated potable water and soil, there are potential initial response plans to provide alternative potable water supply and/or treat water at usage point, restrict access to the contaminated area and/or remove source of contamination. (ASTM, 2015)

Also, since this is a priority number 1 which is an immediate threat to human health, safety, or sensitive environmental receptors then each scenario of BTEX contamination should implement all necessary initial response plan(s) immediately as the contamination is currently negatively affecting the surrounding environment. (ASTM, 2015)



## **6.2 Tier 2 - Evaluation**

In Tier 2 evaluation, site specific target levels (SSTL) are calculated to develop a look-up table which is used to compare to the BTEX chemicals of concern concentration levels found in the soil and groundwater. (ASTM, 2015) Each of the potential exposure pathways has a SSTL calculated and developed for commercial or residential receptors that are potentially at risk to the harmful adverse effects of BTEX. (ASTM, 2015) The exceeded RBSL's exposure pathways from Tier 1 are further developed using detailed specific site data which is collected to calculate the SSTL's for Tier 2 evaluations. (ASTM, 2015)

The SSTL's are calculated based off Equations 1 to 18 located in Chapter 5 with SSTL substituting RBSL in each equation. The equations are the same as in Tier 1 but each parameter has a site specific value assigned instead of the default parameters used in Tier 1 values derived from ASTM. (ASTM, 2015)

Table 6-1 displays the Tier 2 – SSTL Exposure Parameters. These parameters in this table are the same values used in the Tier 1 evaluations as these values are the base line ASTM values for residential and commercial sites. (ASTM, 2015)

The Tier 2 - SSTL Soil, Building, Surface and Subsurface Parameters shown in Table 6-2 display the chemical specific values and site specific values. The chemical specific values are referenced from ASTM and the detailed site specific values are referenced from Happy Valley-Goose Bay regional data from various sources to synthetically demonstrate the collection of site specific data for Tier 2 evaluation. Some site specific values are the same as the default Tier 1 ASTM values because they are assumed to have similar site

specific values compared to default values or the data was not readily available and had to be assumed.

- Lower depth of surficial soil zone is 100 cm deep. Value was selected to be similar to default Tier 1 values. (ASTM, 2015)
- Fraction of organic carbon in soil is 0.015. Value was selected from a range of regional soil data. (Abedin, J., 2015)
- Thickness of capillary fringe is 5 cm. Value was selected to be similar to default Tier 1 values. (ASTM,2015)
- Thickness of vadose zone is 500 cm. Value was selected from a range of regional vadose data. (NEIA, 2008)
- Infiltration rate of water through soil is 100 cm/year. Value was selected to be larger than default Tier 1 values as the regional conditions appear to be higher than the default values and data was not readily available. (ASTM,2015)(NEIA, 2008)
- Depth to subsurface soils is 100 cm. Value was selected to be similar to default Tier 1 values. (ASTM , 2015)
- Particulate emission rate is  $6.90\text{E-}14$  g/cm<sup>2</sup>-s. Value was selected to be similar to default Tier 1 values. (ASTM, 2015)
- Average wind speed above ground surface is 270 cm/s. Value was selected from a range of historical regional wind data. (SNC-Lavalin,2013)
- Groundwater Darcy velocity is 5475 cm/year. Value was selected from a range of regional groundwater data. (NEIA, 2008)
- Width of source area parallel to flow is 1500 cm. Value was selected to be similar to default Tier 1 values. (ASTM, 2015)

- Ambient air mixing zone height is 200 cm. Value was selected to be similar to default Tier 1 values. (ASTM , 2015)
- Groundwater mixing zone thickness is 200 cm. Value was selected to be similar to default Tier 1 values. (ASTM, 2015)
- Total soil porosity is 30%. Value was selected from a range of regional soil porosity data. (NEIA, 2008)
- Volumetric air content in vadose zone is 0.1. Value was selected based off the selected total soil porosity value and the default Tier 1 value. (ASTM,2015)(NEIA, 2008)
- Volumetric water content in vadose zone is 0.2. Value was selected based off the selected total soil porosity value and the default Tier 1 value. (ASTM,2015)(NEIA, 2008)
- Soil bulk density is  $1.8 \text{ g/cm}^3$ . Value was selected from a stated estimated soil density value for a different location in Labrador. Soil bulk density data was not readily available for Happy Valley-Goose Bay. (Aivek Stantec, 2016)
- Averaging time for vapour flux is  $9.46\text{E}+08$  sec for residential and  $7.88\text{E}+08$  sec for commercial. Value was selected to be similar to default Tier 1 values. (ASTM, 2015)

**Table 6-1: Tier 2 - SSTL Exposure Parameters (ASTM, 2015)**

Tier 2 - SSTL Exposure Parameters			
Parameter	Units	Residential	Commercial
AT <sub>c</sub>	years	70	70
AT <sub>n</sub>	years	30	25
BW	kg	70	70
ED	years	30	25
EF	days/year	350	250
IR <sub>soil</sub>	mg/day	100	50
IR <sub>air</sub>	m <sup>3</sup> /day	20	20
IR <sub>w</sub>	L/day	2	1
M	mg/cm <sup>2</sup>	0.5	0.5
RAF <sub>d</sub> - Benzene	unitless	0.05	0.05
RAF <sub>o</sub> - Benzene	unitless	1	1
RfD <sub>i</sub> - Toluene	mg/kg-day	0.2	0.2
RfD <sub>o</sub> - Toluene	mg/kg-day	0.11	0.11
SA	cm <sup>2</sup> /day	3160	3160
SF <sub>i</sub> - Benzene	kg-day/mg	0.029	0.029
SF <sub>o</sub> - Benzene	kg-day/mg	0.029	0.029
THQ	unitless	1	1
TR	unitless	1.00E-06	1.00E-06

**Table 6-2: Tier 2 - SSTL Soil, Building, Surface and Subsurface Parameters**

Tier 2 - SSTL Soil, Building, Surface and Subsurface Parameters			
Parameter	Units	Residential	Commercial
d	cm	100	100
D <sup>air</sup> - Benzene	cm <sup>2</sup> /sec	0.093	0.093
D <sup>wat</sup> - Benzene	cm <sup>2</sup> /sec	1.10E-05	1.10E-05
f <sub>oc</sub>	g-C/g-soil	0.015	0.015
H - Benzene	cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air	0.228	0.228
H -Toluene	cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air	0.272	0.272
h <sub>cap</sub>	cm	5	5
h <sub>v</sub>	cm	500	500
I	cm/year	100	100
logk <sub>oc</sub> - Benzene	cm <sup>3</sup> -H <sub>2</sub> O/g - C	1.58	1.58
logk <sub>oc</sub> - Toluene	cm <sup>3</sup> -H <sub>2</sub> O/g - C	2.13	2.13
k <sub>s</sub> - Benzene	cm <sup>3</sup> -H <sub>2</sub> O/g -soil	0.57	0.57
k <sub>s</sub> - Toluene	cm <sup>3</sup> -H <sub>2</sub> O/g -soil	2.023	2.023
L <sub>GW</sub>	cm	505	505
L <sub>S</sub>	cm	100	100
P <sub>e</sub>	g/cm <sup>2</sup> -s	6.90E-14	6.90E-14
U <sub>air</sub>	cm/s	270	270
U <sub>gw</sub>	cm/year	5475	5475
W	cm	1500	1500
δ <sub>air</sub>	cm	200	200
δ <sub>gw</sub>	cm	200	200
θ <sub>as</sub>	cm <sup>3</sup> /cm <sup>3</sup> -soil	0.1	0.1
θ <sub>T</sub>	cm <sup>3</sup> /cm <sup>3</sup> -soil	0.3	0.3
θ <sub>ws</sub>	cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil	0.2	0.2
ρ	g/cm <sup>3</sup>	1.8	1.8
τ	sec	9.46E+08	7.88E+08

Each of the Tier 2 parameters are input into Equations 1 to 18 located in Chapter 5 to calculate the necessary SSTL's for the exceeded RBSL's from Tier 1. (ASTM, 2015)

Table 6-3 shows the calculated volatilization factors where each of these parameters are input into the SSTL equations to calculate Tier 2 residential and commercial SSTL's.

**Table 6-3: Tier 2 – Calculated SSTL Volatilization Factors**

Tier 2 – Calculated SSTL Volatilization Factors			
Parameter	Definition (Units)	Residential	Commercial
$D_s^{\text{eff}}$ - Benzene	Effective diffusion coefficient in soil based on vapour-phase ( $\text{cm}^2/\text{s}$ )	4.86E-04	4.86E-04
$LF_{\text{sw}}$ - Benzene	Leaching Factor - subsurface to groundwater ( $\text{mg/L}$ / $\text{mg/kg-soil}$ )	0.174	0.174
$LF_{\text{sw}}$ - Toluene	Leaching Factor - subsurface to groundwater ( $\text{mg/L}$ / $\text{mg/kg-soil}$ )	0.056	0.056
$VF_{\text{ss}}$ - Benzene	Volatilization Factor - surficial soils to ambient air vapours ( $\text{mg/m}^3$ -air / $\text{mg/kg-soil}$ )	5.30E-06	6.35E-06
$VF_p$	Volatilization Factor - ambient air particulates ( $\text{mg/m}^3$ -air / $\text{mg/kg-soil}$ )	1.92E-12	1.92E-12
$VF_{\text{samb}}$ - Benzene	Volatilization Factor - subsurface soils to ambient air ( $\text{mg/m}^3$ -air / $\text{mg/kg-soil}$ )	4.44E-05	4.44E-05

Each calculated SSTL value is entered into the Tier 2 look-up table which is compared to the soil and groundwater laboratory samples located in Tables 3-1 to 3-6. (ASTM, 2015)

If the site sample concentration exceeds the SSTL then Tier 3 is implemented or if it is lower than no further action is required as the concentration is below the threshold to cause adverse health and environmental effects. (ASTM, 2015)

The completed Tier 2 SSTL residential and commercial look-up tables are shown in the Tables 6-4 and 6-5.

**Table 6-4: Tier 2 – Calculated SSTL Look-up Table for Residential Sites**

Tier 2 - SSTL Look-up Table					
Residential Sites					
Cancer Target Risk (TR) = 1E-06 , Chronic Hazard Quotient (HQ) =1					
Chemical of Concern	SSTL - Soil Volatilization to Ambient Air (mg/kg)	SSTL - Surficial Soil (mg/kg)	SSTL - Soil Leachate to Groundwater (mg/kg)	SSTL - Groundwater Ingestion (mg/L)	SSTL - Groundwater Volatilization to Ambient Air (mg/L)
Benzene	6.615	x	0.0169	0.00294	x
Toluene	x	x	x	x	x
Ethylbenzene	x	x	x	x	x
Xylene	x	x	x	x	x
x - Not Applicable in Tier 2 Evaluations					

**Table 6-5: Tier 2 – Calculated SSTL Look-up Table for Commercial Sites**

Tier 2 - SSTL Look-up Table					
Commercial Sites					
Cancer Target Risk (TR) = 1E-06 , Chronic Hazard Quotient (HQ) =1					
Chemical of Concern	SSTL - Soil Volatilization to Ambient Air (mg/kg)	SSTL - Surficial Soil (mg/kg)	SSTL - Soil Leachate to Groundwater (mg/kg)	SSTL - Groundwater Ingestion (mg/L)	SSTL - Groundwater Volatilization to Ambient Air (mg/L)
Benzene	11.11	38.55	0.0567	0.00987	x
Toluene	x	x	200.75	x	x
Ethylbenzene	x	x	x	x	x
Xylene	x	x	x	x	x
x - Not Applicable in Tier 2 Evaluations					



## **6.3 Tier 2 – Results**

### **Tier 2 - Gas Station Results**

After comparing the Gas Station's soil and groundwater BTEX concentration data to the Tier 2 SSTL look-up tables, the following Tier 2 SSTL's are exceeded:

- Soil volatilization to ambient air for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the SSTL of 11.11 mg/kg.
- Surficial soil for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the SSTL of 38.55 mg/kg.
- Soil leachate to groundwater for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the SSTL of 0.0567 mg/kg.
- Soil leachate to groundwater for toluene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the SSTL of 200.75 mg/kg.
- Groundwater ingestion for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 groundwater samples exceed the SSTL of 0.00987 mg/L.

## **Tier 2 - Wellness Centre Results**

After comparing the Wellness Centre's soil and groundwater BTEX concentration data to the Tier 2 SSTL look-up tables, the following commercial Tier 2 SSTL's are exceeded:

- Soil leachate to groundwater for benzene in the WC-1, WC-2, and WC-3 soil samples exceed the SSTL of 0.0567 mg/kg.
- Groundwater ingestion for benzene in the WC-1, WC-2, and WC-3 groundwater samples exceed the SSTL of 0.00987 mg/L.

## **Tier 2 - Store Results**

After comparing the Store's soil and groundwater BTEX concentration data to the Tier 2 SSTL look-up tables, the following commercial Tier 2 SSTL's are exceeded:

- Soil leachate to groundwater for benzene in the S-1, S-2, and S-3 soil samples exceed the SSTL of 0.0567 mg/kg.
- Groundwater ingestion for benzene in the S-1, S-2, and S-3 groundwater samples exceed the SSTL of 0.00987 mg/L.

## **Tier 2 - Residential Houses Results**

After comparing the Residential Houses soil and groundwater BTEX concentration data to the Tier 2 SSTL look-up tables, the following residential Tier 2 SSTL's are exceeded:

- Soil leachate to groundwater for benzene in the RH-1, RH-2, and RH-3 soil samples exceed the SSTL of 0.0169 mg/kg.
- Groundwater ingestion for benzene in the RH-1, RH-2, and RH-3 groundwater samples exceed the SSTL of 0.00294 mg/L.

## **Tier 2 - Walking Trail Results**

After comparing the Walking Trail's soil and groundwater BTEX concentration data to the Tier 2 SSTL look-up tables, the following residential Tier 2 SSTL's are exceeded:

- Soil leachate to groundwater for benzene in the WT-1, WT-2, and WT-3 soil samples exceed the SSTL of 0.0169 mg/kg.
- Groundwater ingestion for benzene in the WT-1, WT-2, and WT-3 groundwater samples exceed the SSTL of 0.00294 mg/L.

## **Tier 2 - Pub Results**

After comparing the Pub's soil and groundwater BTEX concentration data to the Tier 2 SSTL look-up tables, the following commercial Tier 2 SSTL's are exceeded:

- Groundwater ingestion for benzene in the P-1, P-2, and P-3 groundwater samples exceed the SSTL of 0.00987 mg/L.

## **6.4 Comparison of Tier 2 to Tier 1**

For the Gas Station, comparing the results of Tier 2 to the results Tier 1, it is identified that both Tier's share the same exceeded results in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil and groundwater samples. They both have exceeded levels of: soil volatilization to ambient air for benzene, surficial soil for benzene, soil leachate to groundwater for benzene, soil leachate to groundwater for toluene, and groundwater ingestion for benzene.

For the Wellness Centre, comparing the results of Tier 2 to the results Tier 1, it is identified that both Tier's share the same exceeded results in the WC-1, WC-2, and WC-3 soil and groundwater samples. They both have exceeded levels of: soil leachate to groundwater for benzene, and groundwater ingestion for benzene.

For the Store, comparing the results of Tier 2 to the results Tier 1, it is identified that the Tier 2 results for soil volatilization to ambient air for benzene is no longer exceeded in the S-1, S-2, and S-3 soil samples as it is in Tier 1. In the S-1, S-2, and S-3 soil and groundwater samples they both have exceeded levels of: soil leachate to groundwater for benzene, and groundwater ingestion for benzene.

For the Residential Houses, comparing the results of Tier 2 to the results Tier 1, it is identified that both Tier's share the same exceeded results in the RH-1, RH-2, and RH-3 soil and groundwater samples. They both have exceeded levels of: soil leachate to groundwater for benzene, and groundwater ingestion for benzene.

For the Walking Trail, comparing the results of Tier 2 to the results Tier 1, it is identified that the Tier 2 results for soil volatilization to ambient air for benzene is no longer

exceeded in the WT-1, WT-2, and WT-3 soil samples as it is in Tier 1. In the WT-1, WT-2, and WT-3 soil and groundwater samples they both have exceeded levels of: soil leachate to groundwater for benzene, and groundwater ingestion for benzene.

For the Pub, comparing the results of Tier 2 to the results Tier 1, both Tiers' share the same exceeded results in the P-1, P-2, and P-3 groundwater samples. They both have exceeded levels of groundwater ingestion for benzene.

## **Chapter 7: Tier 3**

### **7.1 Site Classification and Initial Response Plan**

In Tier 3, the site must be reclassified (ASTM, 2015) and from Site Classification and Initial Response Plan Priority Criteria from Chapter 4 that this particular case study in Happy Valley-Goose Bay is a priority number 1 case scenario which is the highest ranked threat. (ASTM, 2015)

It is a priority number 1 because from Table 4-1 located in Chapter 4 and from the contaminated Happy Valley – Goose Bay site information that BTEX has impacted or immediately contaminated an active public potable water supply well, line, or intake and the ambient BTEX vapour concentrations surpass the BTEX levels from a safety point of view with respect to Tier 2 SSTL's. (ASTM, 2015)

In this scenario the initial response plan is to notify authorities, property owners, and potentially affected parties about the adverse health and environmental risks in the area. (ASTM, 2015) In regards to the contaminated potable water and soil, there are potential initial response plans to provide alternative potable water supply and/or treat water at usage point, restrict access to the contaminated area and/or remove source of contamination. (ASTM, 2015)

Also, since this is a priority number 1 which is an immediate threat to human health, safety, or sensitive environmental receptors then each scenario of BTEX contamination should implement all necessary initial response plan(s) immediately as the contamination is currently negatively affecting the surrounding environment. (ASTM, 2015)

## 7.2 Tier 3 - Evaluation

In Tier 3 evaluation, site specific target levels (SSTL) are calculated to develop a look-up table which is used to compare to the BTEX chemicals of concern concentration levels found in the soil and groundwater. (ASTM, 2015) Each of the potential exposure pathways has a SSTL calculated and developed for a commercial or residential receptor that is potentially at risk to the harmful adverse effects of BTEX. (ASTM, 2015) The exceeded STSL's exposure pathways from Tier 2 are further developed using extensive detailed specific site data which is collected to calculate the SSTL's for Tier 3 evaluations. (ASTM, 2015) The Tier 3 evaluation is very complex and may require probabilistic evaluations, additional site assessment, and complicated chemical fate and transport models. (ASTM, 2015)

The SSTL's are calculated off Equations 1 to 18 located in Chapter 5 with SSTL substituting RBSL in each equation. The equations are the same as in Tier 1 and 2 with certain non-fixed parameters having their own mean, standard deviation, coefficient of variance, and distribution assigned instead of the default values used in Tier 1 from ASTM and the general specific site data from Tier 2. (ASTM, 2015)

In Tier 3, each SSTL equation is entered into a computational program (ASTM, 2015) called @RISK. This particular software is a Microsoft Excel add-on developed by Palisade to perform risk analysis using Monte Carlo simulation. @RISK is powerful tool to mathematically show the user all possible outcomes for any risk scenario and the chance of potential risks, resulting in a more consistent decision making process under uncertainty. (Palisade, 2019)

Monte Carlo simulation performed in @RISK allows the user to perform risk analysis through implementation of probability distributions, which substitutes a range of values for any parameter that has any uncertainty. (Palisade, 2019) The Monte Carlo simulation is iterated many times, which potentially could involve anywhere from hundreds to tens of thousands iterations where each calculation implements a different set of random parameter values from the input probability distributions. (Palisade, 2019)

In order to properly use @RISK for Tier 3 evaluation, there is intensive specific site data collection required compared to Tier 2 evaluation. (ASTM, 2015) In Tier 2, a single specific site data value is used to calculate Tier 2 SSTL's. Whereas in Tier 3, numerous specific site data is extensively collected to precisely distribute any uncertainty parameter. (ASTM, 2015) These parameters are entered into @RISK where Monte Carlo simulations provide highly confident Tier 3 SSTL's which are compared to the soil and groundwater samples. (ASTM, 2015) Each uncertain parameter value is collected extensively to develop an accurate model of the parameters mean and standard deviation. (ASTM, 2015)

For example, if the groundwater Darcy velocity is required for Tier 3 evaluation then the groundwater velocity would be measured and monitored in various locations across the specific site constantly throughout the year(s) to collect precise groundwater velocity data utilized in Tier 3 SSTL calculations. This data is used to confidently measure changes in groundwater velocity due to climate and weather, whereas Tier 2 data is a single value without any distribution.

Tables 7-1 to 7-4 show the Tier 3 – SSTL Exposure Parameters and Tier 3 - SSTL Soil, Building, Surface and Subsurface Parameters for residential and commercial receptors



where each parameter displays: mean, standard deviation, coefficient of variance, and whether it is distributed or a fixed value. The detailed site specific Tier 3 parameter data is based off the Tier 2 site specific values used in this case study in Happy Valley-Goose Bay and since the sites contamination scenario is fabricated then a coefficient of variance is introduced to simulate the extensive data collection required.

The site specific data used and collected in Tier 2 is used as the Tier 3 residential or commercial mean. The created coefficient of variance of 10% or 20% for non-seasonal and seasonal factors respectively is used to generate the standard deviation. The value of 10% is chosen to represent slight changes throughout the specific Happy Valley-Goose Bay region and 20% was chosen to represent the changes in climate and weather throughout the year. The distributions are either fixed for non-variables, lognormal for yearly time variables, and normal for the remaining natural measured variables.

**Table 7-1: Tier 3 – SSTL Residential Exposure Parameters**

Tier 3 - SSTL Residential Exposure Parameters					
Parameter	Units	Residential Mean $\mu$	Residential Standard Deviation $\sigma$	Coefficient of Variance	Distribution
AT <sub>c</sub>	years	70	7	10%	Lognormal
AT <sub>n</sub>	years	30	3	10%	Lognormal
BW	kg	70	7	10%	Normal
ED	years	30	3	10%	Lognormal
EF	days/year	350	35	10%	Lognormal
IR <sub>soil</sub>	mg/day	100	10	10%	Normal
IR <sub>air</sub>	m <sup>3</sup> /day	20	2	10%	Normal
IR <sub>w</sub>	L/day	2	0.2	10%	Normal
M	mg/cm <sup>2</sup>	0.5	0.05	10%	Normal
RAF <sub>d</sub> - Benzene	unitless	0.05	X	X	Fixed
RAF <sub>o</sub> - Benzene	unitless	1	X	X	Fixed
RfD <sub>i</sub> - Toluene	mg/kg-day	0.2	X	X	Fixed
RfD <sub>o</sub> - Toluene	mg/kg-day	0.11	X	X	Fixed
SA	cm <sup>2</sup> /day	3160	316	10%	Normal
SF <sub>i</sub> - Benzene	kg-day/mg	0.029	X	X	Fixed
SF <sub>o</sub> - Benzene	kg-day/mg	0.029	X	X	Fixed
THQ	unitless	1	X	X	Fixed
TR	unitless	1.00E-06	X	X	Fixed

**Table 7-2: Tier 3 – SSTL Residential Soil, Building, Surface and Subsurface Parameters**

Tier 3 - SSTL Residential Soil, Building, Surface and Subsurface Parameters					
Parameter	Units	Residential Mean $\mu$	Residential Standard Deviation $\sigma$	Coefficient of Variance	Distribution
d	cm	100	10	10%	Normal
D <sup>air</sup> - Benzene	cm <sup>2</sup> /sec	0.093	X	X	Fixed
D <sup>wat</sup> - Benzene	cm <sup>2</sup> /sec	1.10E-05	X	X	Fixed
f <sub>oc</sub>	g-C/g-soil	0.015	0.0015	10%	Normal
H - Benzene	cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air	0.228	X	X	Fixed
H -Toluene	cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air	0.272	X	X	Fixed
h <sub>cap</sub>	cm	5	0.5	10%	Normal
h <sub>v</sub>	cm	500	50	10%	Normal
I	cm/year	100	20	20% (seasonal)	Normal
logk <sub>oc</sub> - Benzene	cm <sup>3</sup> -H <sub>2</sub> O/g - C	1.58	X	X	Fixed
logk <sub>oc</sub> - Toluene	cm <sup>3</sup> -H <sub>2</sub> O/g - C	2.13	X	X	Fixed
k <sub>s</sub> - Benzene	cm <sup>3</sup> -H <sub>2</sub> O/g -soil	0.57	0.057	10%	Normal
k <sub>s</sub> - Toluene	cm <sup>3</sup> -H <sub>2</sub> O/g -soil	2.023	0.2023	10%	Normal
L <sub>GW</sub>	cm	505	50.5	10%	Normal
L <sub>S</sub>	cm	100	10	10%	Normal
P <sub>e</sub>	g/cm <sup>2</sup> -s	6.90E-14	6.90E-15	10%	Normal
U <sub>air</sub>	cm/s	270	54	20% (seasonal)	Normal
U <sub>gw</sub>	cm/year	5475	1095	20% (seasonal)	Normal
W	cm	1500	150	10%	Normal
δ <sub>air</sub>	cm	200	20	10%	Normal
δ <sub>gw</sub>	cm	200	20	10%	Normal
θ <sub>as</sub>	cm <sup>3</sup> /cm <sup>3</sup> -soil	0.1	0.01	10%	Normal
θ <sub>T</sub>	cm <sup>3</sup> /cm <sup>3</sup> -soil	0.3	0.03	10%	Normal
θ <sub>ws</sub>	cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil	0.2	0.02	10%	Normal
ρ	g/cm <sup>3</sup>	1.8	0.18	10%	Normal
τ	sec	9.46E+08	9.46E+07	10%	Normal

**Table 7-3: Tier 3 – SSTL Commercial Exposure Parameters**

Tier 3 - SSTL Commercial Exposure Parameters					
Parameter	Units	Commercial Mean $\mu$	Commercial Standard Deviation $\sigma$	Coefficient of Variance	Distribution
AT <sub>c</sub>	years	70	7	10%	Lognormal
AT <sub>n</sub>	years	25	2.5	10%	Lognormal
BW	kg	70	7	10%	Normal
ED	years	25	2.5	10%	Lognormal
EF	days/year	250	25	10%	Lognormal
IR <sub>soil</sub>	mg/day	50	5	10%	Normal
IR <sub>air</sub>	m <sup>3</sup> /day	20	2	10%	Normal
IR <sub>w</sub>	L/day	1	0.1	10%	Normal
M	mg/cm <sup>2</sup>	0.5	0.05	10%	Normal
RAF <sub>d</sub> - Benzene	unitless	0.05	X	X	Fixed
RAF <sub>o</sub> - Benzene	unitless	1	X	X	Fixed
RfD <sub>i</sub> - Toluene	mg/kg-day	0.2	X	X	Fixed
RfD <sub>o</sub> - Toluene	mg/kg-day	0.11	X	X	Fixed
SA	cm <sup>2</sup> /day	3160	316	10%	Normal
SF <sub>i</sub> - Benzene	kg-day/mg	0.029	X	X	Fixed
SF <sub>o</sub> - Benzene	kg-day/mg	0.029	X	X	Fixed
THQ	unitless	1	X	X	Fixed
TR	unitless	1.00E-06	X	X	Fixed

**Table 7-4: Tier 3 – SSTL Commercial Soil, Building, Surface, and Subsurface Parameters**

Tier 3 - SSTL Commercial Soil, Building, Surface and Subsurface Parameters					
Parameter	Units	Commercial Mean $\mu$	Commercial Standard Deviation $\sigma$	Coefficient of Variance	Distribution
d	cm	100	10	10%	Normal
D <sup>air</sup> - Benzene	cm <sup>2</sup> /sec	0.093	X	X	Fixed
D <sup>wat</sup> - Benzene	cm <sup>2</sup> /sec	1.10E-05	X	X	Fixed
f <sub>oc</sub>	g-C/g-soil	0.015	0.0015	10%	Normal
H - Benzene	cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air	0.228	X	X	Fixed
H -Toluene	cm <sup>3</sup> -H <sub>2</sub> O/ cm <sup>3</sup> -air	0.272	X	X	Fixed
h <sub>cap</sub>	cm	5	0.5	10%	Normal
h <sub>v</sub>	cm	500	50	10%	Normal
I	cm/year	100	20	20% (seasonal)	Normal
logk <sub>oc</sub> - Benzene	cm <sup>3</sup> -H <sub>2</sub> O/g - C	1.58	X	X	Fixed
logk <sub>oc</sub> - Toluene	cm <sup>3</sup> -H <sub>2</sub> O/g - C	2.13	X	X	Fixed
k <sub>s</sub> - Benzene	cm <sup>3</sup> -H <sub>2</sub> O/g -soil	0.57	0.057	10%	Normal
k <sub>s</sub> - Toluene	cm <sup>3</sup> -H <sub>2</sub> O/g -soil	2.023	0.2023	10%	Normal
L <sub>GW</sub>	cm	505	50.5	10%	Normal
L <sub>S</sub>	cm	100	10	10%	Normal
P <sub>e</sub>	g/cm <sup>2</sup> -s	6.90E-14	6.90E-15	10%	Normal
U <sub>air</sub>	cm/s	270	54	20% (seasonal)	Normal
U <sub>gw</sub>	cm/year	5475	1095	20% (seasonal)	Normal
W	cm	1500	150	10%	Normal
δ <sub>air</sub>	cm	200	20	10%	Normal
δ <sub>gw</sub>	cm	200	20	10%	Normal
θ <sub>as</sub>	cm <sup>3</sup> /cm <sup>3</sup> -soil	0.1	0.01	10%	Normal
θ <sub>T</sub>	cm <sup>3</sup> /cm <sup>3</sup> -soil	0.3	0.03	10%	Normal
θ <sub>ws</sub>	cm <sup>3</sup> -H <sub>2</sub> O/cm <sup>3</sup> -soil	0.2	0.02	10%	Normal
ρ	g/cm <sup>3</sup>	1.8	0.18	10%	Normal
τ	sec	7.88E+08	7.88E+07	10%	Normal

Using Equations 1 to 18 located in Chapter 5 (with SSTL substituting RBSL in each equation), each of the Tier 3 parameters: mean, standard deviation and distribution are entered into @RISK software to calculate a 95% confidence interval value. This selected interval assures the user that the calculated value contains the true population mean.

(Graphpad, 2017) The 95 % confidence interval is calculated in @RISK through the use of ten thousand Monte Carlo simulations, the input data is confidently calculated numerous times to converge on the 95% confidence interval values needed for Tier 3 evaluations.

Each calculated 95% confidence interval SSTL is entered into the Tier 3 look-up table which is compared to the soil and groundwater laboratory samples located in Tables 3-1 and 3-6. (ASTM, 2015) If the site sample concentration exceeds the SSTL then remediation is implemented or if it is lower than no further action is required as the concentration is below the threshold to cause adverse health and environmental effects. (ASTM, 2015)

Tables 7-5 shows the calculated volatilization factors where each of these parameters are input into the SSTL equations to calculate Tier 3 residential and commercial SSTL's.

The completed Tier 3 SSTL residential and commercial look-up tables are shown in the Tables 7-6 and 7-7.

**Table 7-5: Tier 3 – Calculated SSTL Volatilization Factors**

Tier 3 - Calculated SSTL Volatilization Factors			
Parameter	Definition (Units)	Residential	Commercial
$D_s^{\text{eff}}$ - Benzene	Effective diffusion coefficient in soil based on vapour-phase ( $\text{cm}^2/\text{s}$ )	6.391E-04	6.391E-04
$LF_{\text{sw}}$ - Benzene	Leaching Factor - Subsurface to groundwater ( $\text{mg/L}$ / $\text{mg/kg-soil}$ )	0.24729	0.24729
$LF_{\text{sw}}$ - Toluene	Leaching Factor - Subsurface to groundwater ( $\text{mg/L}$ / $\text{mg/kg-soil}$ )	0.079468	0.079468
$VF_{\text{ss}}$ - Benzene	Volatilization Factor - Surficial Soils to ambient air vapours ( $\text{mg/m}^3$ -air / $\text{mg/kg}$ -soil)	9.118E-06	1.082E-05
$VF_p$	Volatilization Factor - ambient air particulates ( $\text{mg/m}^3$ -air / $\text{mg/kg}$ -soil)	3.117E-12	3.117E-12
$VF_{\text{samb}}$ - Benzene	Volatilization Factor - subsurface soils to ambient air ( $\text{mg/m}^3$ -air / $\text{mg/kg}$ -soil)	9.614E-05	9.614E-05

**Table 7-6: Tier 3 – SSTL Look-up Table for Residential Sites**

Tier 3 - SSTL Look-up Table					
Residential Sites					
Cancer Target Risk (TR) = 1E-06 , Chronic Hazard Quotient (HQ) =1					
Chemical of Concern	SSTL - Soil Volatilization to Ambient Air (mg/kg)	SSTL - Surficial Soil (mg/kg)	SSTL - Soil Leachate to Groundwater (mg/kg)	SSTL - Groundwater Ingestion (mg/L)	SSTL - Groundwater Volatilization to Ambient Air (mg/L)
Benzene	3.8425	x	0.014889	0.0036818	x
Toluene	x	x	x	x	x
Ethylbenzene	x	x	x	x	x
Xylene	x	x	x	x	x
x - Not Applicable in Tier 3 Evaluations					

**Table 7-7: Tier 3 – SSTL Look-up Table for Commercial Sites**

Tier 3 - SSTL Look-up Table					
Commercial Sites					
Cancer Target Risk (TR) = 1E-06 , Chronic Hazard Quotient (HQ) =1					
Chemical of Concern	SSTL - Soil Volatilization to Ambient Air (mg/kg)	SSTL - Surficial Soil (mg/kg)	SSTL - Soil Leachate to Groundwater (mg/kg)	SSTL - Groundwater Ingestion (mg/L)	SSTL - Groundwater Volatilization to Ambient Air (mg/L)
Benzene	6.452	34.836	0.0498	0.012314	x
Toluene	x	x	177.971	x	x
Ethylbenzene	x	x	x	x	x
Xylene	x	x	x	x	x
x - Not Applicable in Tier 3 Evaluations					



## **7.3 Tier 3 - Results**

### **Tier 3 - Gas Station Results**

After comparing the Gas Station's soil and groundwater BTEX concentration data to the Tier 3 SSTL look-up tables, the following Tier 3 SSTL's are exceeded:

- Soil volatilization to ambient air for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the SSTL of 6.452 mg/kg.
- Surficial soil for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the SSTL of 34.836 mg/kg.
- Soil leachate to groundwater for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the SSTL of 0.0498 mg/kg.
- Soil leachate to groundwater for toluene in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil samples exceed the SSTL of 177.971 mg/kg.
- Groundwater ingestion for benzene in the GS-1, GS-2, GS-3, GS-4, and GS-5 groundwater samples exceed the SSTL of 0.012314 mg/L.

### **Tier 3 - Wellness Centre Results**

After comparing the Wellness Centre's soil and groundwater BTEX concentration data to the Tier 3 SSTL look-up tables, the following commercial Tier 3 SSTL's are exceeded:

- Soil leachate to groundwater for benzene in the WC-1, WC-2, and WC-3 soil samples exceed the SSTL of 0.0498 mg/kg.
- Groundwater ingestion for benzene in the WC-1, WC-2, and WC-3 groundwater samples exceed the SSTL of 0.012314 mg/L.

### **Tier 3 - Store Results**

After comparing the Store's soil and groundwater BTEX concentration data to the Tier 3 SSTL look-up tables, the following commercial Tier 3 SSTL's are exceeded:

- Soil leachate to groundwater for benzene in the S-1, S-2, and S-3 soil samples exceed the SSTL of 0.0498 mg/kg.
- Groundwater ingestion for benzene in the S-1, S-2, and S-3 groundwater samples exceed the SSTL of 0.012314 mg/L.

### **Tier 3 - Residential Houses Results**

After comparing the Residential Houses soil and groundwater BTEX concentration data to the Tier 3 SSTL look-up tables, the following residential Tier 3 SSTL's are exceeded:

- Soil leachate to groundwater for benzene in the RH-1, RH-2, and RH-3 soil samples exceed the SSTL of 0.014889 mg/kg.
- Groundwater ingestion for benzene in the RH-1, RH-2, and RH-3 groundwater samples exceed the SSTL of 0.0036818 mg/L.

### **Tier 3 - Walking Trail Results**

After comparing the Walking Trail's soil and groundwater BTEX concentration data to the Tier 3 SSTL look-up tables, the following residential Tier 3 SSTL's are exceeded:

- Soil leachate to groundwater for benzene in the WT-1, WT-2, and WT-3 soil samples exceed the SSTL of 0.014889 mg/kg.
- Groundwater ingestion for benzene in the WT-1, WT-2, and WT-3 groundwater samples exceed the SSTL of 0.0036818 mg/L.

### **Tier 3 - Pub Results**

After comparing the Pub's soil and groundwater BTEX concentration data to the Tier 3 SSTL look-up tables, the following commercial Tier 3 SSTL's are exceeded:

- Groundwater ingestion for benzene in the P-3 groundwater sample exceeds the SSTL of 0.012314 mg/L.

#### **7.4 Comparison of Tier 3 to Tier 2**

For the Gas station, comparing the results of Tier 3 to the results Tier 2, it is identified that both Tier's share the same exceeded results in the GS-1, GS-2, GS-3, GS-4, and GS-5 soil and groundwater samples. They both have exceeded levels of: soil volatilization to ambient air for benzene, surficial soil for benzene, soil leachate to groundwater for benzene, soil leachate to groundwater for toluene, and groundwater ingestion for benzene.

For the Wellness Centre, comparing the results of Tier 3 to the results Tier 2, it is identified that both Tier's share the same exceeded results in the WC-1, WC-2, and WC-3 soil and groundwater samples. They both have exceeded levels of: soil leachate to groundwater for benzene, and groundwater ingestion for benzene.

For the Store, comparing the results of Tier 3 to the results Tier 2, it is identified that both Tier's share the same exceeded results in the S-1, S-2, and S-3 soil and groundwater samples. They both have exceeded levels of: soil leachate to groundwater for benzene, and groundwater ingestion for benzene.

For the Residential Houses, comparing the results of Tier 3 to the results Tier 2, it is identified that both Tier's share the same exceeded results in the RH-1, RH-2, and RH-3 soil and groundwater samples. They both have exceeded levels of: soil leachate to groundwater for benzene, and groundwater ingestion for benzene.

For the Walking Trail, comparing the results of Tier 3 to the results Tier 2, it is identified that both Tier's share the same exceeded results in the WT-1, WT-2, and WT-3 soil and

groundwater samples. They both have exceeded levels of: soil leachate to groundwater for benzene, and groundwater ingestion for benzene.

For the Pub, comparing the results of Tier 3 to the results Tier 2, it is identified that the groundwater ingestion for benzene is no longer exceeded in the P-1 and P-2 groundwater samples as it is in Tier 2. In the P-3 groundwater sample there is an exceeded level of groundwater ingestion for benzene in both Tier 2 and Tier 3.

## **Chapter 8: Remediation**

### **8.1 Remediation Technologies**

If any of the BTEX sample concentrations collected from a contaminated site are higher than the Tier 3 SSTL's at the source area and/or any points of compliance, then a remediation action plan is required in order to lower the health and environmental risks of BTEX contamination. (ASTM, 2015) Remediation is implemented to lower the site BTEX concentrations to become equal or below the Tier 3 SSTL's and once remediation is selected and installed, there must be a compliance monitoring plan developed to ensure the remediation goals are being satisfied. (ASTM, 2015) Once remediation has reached the required concentration and there is no further need for compliance monitoring on site, then the site requires no further action. (ASTM, 2015)

There are various soil and groundwater remediation technologies available for BTEX contamination. (USEPA, 1994) Each of the remediation methods operate differently and are dependent on many factors to select the optimal choice. The chosen soil and groundwater remediation is dependent on degree of environmental impact, site conditions, volume of contamination area, concentration levels, cost, feasibility, stakeholder's preference, remediation time, and many other scenarios. (USEPA, 1994)

The specific site in the Happy Valley-Goose Bay case study, there are sample BTEX soil and groundwater concentrations that exceed the developed Tier 3 SSTL's. The exceeded concentration levels require remediation in order to reach the desired SSTL's. (ASTM, 2015) To remediate the specific site's contaminated soil and groundwater, three potential soil and three potential groundwater remediation technologies are discussed to finally

select one soil and one groundwater remediation technology with the purpose to optimally reduce adverse health and environmental risks.

The three potential soil remediation technologies to reduce the exceeded BTEX concentrations are soil vapour extraction, soil flushing, and bioventing. The three potential groundwater remediation technologies are pump and treat, air sparging, and biosparging. Each of these technologies has advantages and disadvantages when selecting the optimal remediation method.

Soil vapour extraction (SVE) is an in situ soil remediation technology that aids in the removal of organic contaminants such as BTEX. (USEPA, 1994) SVE induces a pressure gradient in the unsaturated zone through the installation of vacuum blowers and vertical and/or horizontal wells which aids in the removal of volatile organic contaminants from the contaminated site. (USEPA, 1994) The vacuum aids in the evaporation of volatile contaminants in which extracted vapours are directed to the surface where they are treated and released into the atmosphere. (USEPA, 1994) SVE remediation generally costs \$20-50(USD) per ton of contaminated soil (Tyagi, R.D., 2007)

There are many advantages to SVE remediation technology. SVE is a proven technology and the necessary equipment is easy to obtain and install. (USEPA, 1994) SVE has minimal site disturbance during operation and removal. (USEPA, 1994) SVE is cost effective and has relatively short treatment times of 6 months to 2 years under optimal site conditions) and this technology is used easily with other remediation technologies to enhance remediation time. (USEPA, 1994) SVE is more effective in contaminated sites with high permeability soils. (USEPA, 1994)

There are also many disadvantages to SVE remediation technology. Contaminant concentrations reductions higher than 90% are challenging to accomplish with SVE technology. (USEPA, 1994) SVE usually requires air emission permits and may also require expensive treatment atmospheric discharge of extracted vapours. (USEPA, 1994) SVE is less effective in contaminated sites with low permeability soils. (USEPA, 1994) Also, SVE only remediates the vadose zone and is dependent on other remediation technologies to remediate saturated zone soils and groundwater. (Tyagi, R.D., 2007)

Soil flushing is an in situ soil remediation technology that aids in the removal of organic contaminants such as BTEX. (USEPA, 2006) Soil flushing involves flooding the contaminated area with a specifically selected solution to remove contaminants. (USEPA, 2006) A liquid solution or water is entered into injection wells which direct flow into the contaminated area resulting in mobilization of contaminants through solubilization, emulsion formations, or chemical reactions. (USEPA, 2006) The liquid solution is passed through the contaminated area collecting contaminants directed into the extraction wells where it is brought back to the surface for treatment or disposal (USEPA, 2006). Soil flushing remediation generally costs \$75-\$300(USD) per cubic yard of contamination plume. (Tyagi, R.D., 2007)

In situ soil flushing has many advantages in remediation of contaminants such as BTEX. Soil flushing minimizes the amount of soil that requires treatment or disposal. (Tyagi, R.D., 2007) Under optimal operating conditions, soil flushing can lead to removal of 90% of contaminated area. (Tyagi, R.D., 2007) Once free of contaminants, the treated flushed soil is either returned to the site or is recycled for other uses. (Tyagi, R.D., 2007) Since



this method is in situ then the pH, temperature, and many other variables are measured on site which saves time and cost (Tyagi, R.D., 2007)

There also many disadvantages in selecting in situ soil flushing. This method demands a large area in order to implement this technology, operation costs are generally very high and is usually used on large contamination sites. (Tyagi, R.D., 2007) Due to the speed of the diffusion process, remediation generally takes much more time compared to other technologies. (Tyagi, R.D., 2007) There are also various risks of added contamination such as pollution from wastewater treatment, spills, etc. (Tyagi, R.D., 2007)

Bioventing is an in situ soil remediation technology that aids in the removal of organic contaminants such as BTEX. (USEPA, 1995) Bioventing involves injecting air into the vadose zone through injection wells to stimulate biological activity and allow biodegradation of the contaminants. (USEPA, 1995) The injected air stimulates the indigenous microorganisms which results in maximizing biodegradation and minimizing volatilization allowing the microorganisms to ingest the contaminants and decompose them into safe chemical compounds. (USEPA, 1995) Bioventing generally costs \$45-\$140(USD) per cubic ton of contaminated soil. (Tyagi, R.D., 2007)

Bioventing has many advantages in remediation of contaminants such as BTEX. Bioventing remediation's necessary equipment is easy to obtain and install. (Tyagi, R.D., 2007) Bioventing has minimal site disturbance during operation and removal and is easily integrated with other remediation technologies. (Tyagi, R.D., 2007) Bioventing is also cost effective and has relatively short treatment times of 6 months to 2 years under

optimal site conditions. (Tyagi, R.D., 2007) It has the ability for effective use in areas of high permeable soil. (Tyagi, R.D., 2007).

Bioventing remediation also has many disadvantages in removing contaminants. If the contaminant concentrations are too high then the microorganisms can become toxic and inhibit further growth and delay remediation. (Tyagi, R.D., 2007) Also, if the contaminant concentrations are too low then it is very difficult to remove the contaminants. (Tyagi, R.D., 2007) Bioventing is very dependent on temperatures in which low temperatures result in slower remediation rates and is less effective in contaminated sites with low permeability soils. (Tyagi, R.D., 2007) Bioventing is dependent on the type and amount of indigenous microorganisms in the contaminated soil. (Tyagi, R.D., 2007)

Pump and treat is an in situ groundwater remediation technology that aids in the removal of organic contaminants such as BTEX. (USEPA, 2012c) Pump and treat remediation involves pumping the contaminated groundwater into the installed extraction wells which directs the contaminated groundwater to the surface which is then remediated in the treatment system implemented on site. (USEPA, 2012c) The treated groundwater has the option for safe disposal or for other uses. (USEPA, 2012c) Pump and treat costs have a vast range and is different for each specific site. A typical 100 gallons per minute system has installation and design cost of \$200,000 (USD) with operating and maintenance costs of \$1-\$100 (USD) per 1000 gallons of groundwater. (Pacific Northwest National Laboratory, 1994)

Pump and treat has many advantages in remediation of contaminants such as BTEX.

Pump and treat necessary equipment is easy to obtain, install, design, and operate. (Khan,

F.I., Husain, T., Hejazi, R., 2004) It has minimal site disturbance during operation and removal and is easily integrated with other remediation technologies. (Khan, F.I., Husain, T., Hejazi, R., 2004) Also, pump and treat is very effective in hard water. (Pacific Northwest National Laboratory, 1994)

Pump and treat groundwater remediation also has many disadvantages in removing contaminants. The cost of remediation is usually very high compared to other remediation options and remediation time is slow where it usually takes a few years to decades to reach desired concentrations. (Khan, F.I., Husain, T., Hejazi, R., 2004) Also, pump and treat remediation of potable drinking water to safe concentration levels are often not met. (Pacific Northwest National Laboratory, 1994)

Air sparging is an in situ groundwater remediation technology that aids in the removal of organic contaminants such as BTEX. (NAVFAC, 2001) Air sparging remediation involves injecting air directly into the saturated zone or groundwater to remove volatile organic contaminants from the dissolved phase to the vapour phase by use of air stripping. (NAVFAC, 2001) The stripped contaminants are sent to the vadose zone for biodegradation and/or collected from other soil remediation technologies such as SVE. (NAVFAC, 2001) Air sparging remediation technology generally costs \$20-\$50 (USD) per ton of saturated soil. (USEPA, 1994)

Air sparging has many advantages in remediation of contaminants such as BTEX. The necessary remediation equipment for air sparging is easy to obtain and install. (USEPA, 1994) Air sparging has minimal site disturbance during operation and removal and is easily integrated with other remediation technologies, usually SVE which enhances

remediation efficiency. (USEPA, 1994) Air sparging is also cost effective compared to other groundwater remediation technologies and has relatively short treatment times less than 1 to 3 years under optimal site conditions. (USEPA, 1994) It also requires no removal, treatment, or discharge considerations for groundwater which reduces remediation time, efficiency, and cost. (USEPA, 1994)

Air sparging remediation also has many disadvantages in removing contaminants. If the contaminants involve free product then it must be removed before air sparging commences. (USEPA, 1994) Air sparging is unable for implementation in confined aquifers and stratified soils may result in very low remediation efficiency. (USEPA, 1994) The potential for unpredictable transport of contaminant plume and creation of harmful surface vapours are possible. (USEPA, 1994) Also, air sparging requires detailed monitoring to ensure vapour control and limit mobilization of contaminant plume. (USEPA, 1994)

Biosparging is an in situ groundwater remediation technology that aids in the removal of organic contaminants such as BTEX. (USEPA, 1994) Biosparging remediation involves injecting air and nutrients (if required) into the saturated groundwater zone at low flow rates to stimulate indigenous microorganism activity. (USEPA, 1994) The stimulated microorganism's aid in biodegradation of the organic contaminants dissolved in the groundwater, adsorbed to soil below water table, and within capillary fringe by ingesting the contaminants and decomposing them into safe chemical compounds. (USEPA, 1994) Biosparging is usually combined with other soil remediation technologies such as SVE. (USEPA, 1994) Biosparging remediation technology generally costs \$15-\$30 (USD) per cubic metre of treated groundwater. (Hemant, J. et al., 2017)

Biosparging has many advantages in remediation of contaminants such as BTEX. The necessary remediation equipment for biosparging is easy to obtain and install. (USEPA, 1994) Biosparging has minimal site disturbance during operation and removal and is easily integrated with other remediation technologies, usually SVE which enhances remediation efficiency. (USEPA, 1994) Biosparging is also cost effective compared to other groundwater remediation technologies and has relatively short treatment times of 6 months to 2 years under optimal site conditions. (USEPA, 1994) It also requires no removal, treatment, or discharge considerations for groundwater which reduces remediation time, efficiency, and cost. (USEPA, 1994)

Biosparging remediation also has many disadvantages in removing contaminants. If the contaminants involves free product then it must be removed before biosparging commences. (USEPA, 1994) Biosparging is unable for commencement in confined aquifers and stratified soils may result in very low remediation efficiency. (USEPA, 1994) The potential for unpredictable transport of contaminant plume and creation of harmful surface vapours are possible.. (USEPA, 1994) Also, the chemical, physical, and biological interaction process with the contaminant and microorganisms are not well understood as unpredictable microorganism movement could result in random biodegradation rates. (USEPA, 1994) To ensure remediation is occurring, monitoring of the remediation is necessary. (USEPA, 1994)

Indigenous microorganism growth is dependent on temperature and is known to decrease significantly at groundwater temperatures below ten degrees Celsius. (USEPA, 1994)

## 8.2 Remediation Selection for Case Study

Comparing the potential soil remediation technologies, soil vapour extraction (SVE) is selected over soil flushing and bioventing to remediate the exceeded soil BTEX concentrations. Also, comparing the potential groundwater remediation technologies, air sparging is selected over pump and treat and biosparging to remediate the exceeded groundwater BTEX concentrations. These selected soil and groundwater remediation technologies will also be implemented and installed together to increase remediation efficiency. (USEPA, 1994)

SVE is selected to remediate the exceeded BTEX concentrations found in the soil because it is a proven technology and the necessary equipment is easy to obtain and install with minimal site disturbance allowing remediation to commence as soon as possible.

(USEPA, 1994) SVE is also selected due its relatively short remediation times and its ability for implementation with other technologies such as air sparging. (USEPA, 1994)

Due to the high permeable soil in Happy Valley-Goose Bay, NL (NEIA, 2008) then SVE has the capability for effective use at this specific site.

SVE is selected over soil flushing because soil flushing remediation's operation costs are generally very high and remediation time is generally much longer compared to SVE.

(USEPA, 1994),(USEPA, 2006), (Tyagi, R.D., 2007)

SVE is selected over bioventing because bioventing is very dependent on temperature (Tyagi, R.D., 2007) and due to Happy Valley-Goose Bay's climate which is relatively cold then it not recommended to utilize bioventing since remediation time is much longer than SVE for this particular case study. Also, some BTEX concentrations may have

exceeded concentration levels for the indigenous microorganisms resulting in the potential of delayed remediation and toxicity of the microorganisms. (Tyagi, R.D., 2007)

Although contaminant reductions greater than 90% are challenging to accomplish with SVE alone, this technology has the ability for combination with other remediation technologies such as air sparging to increase remediation efficiency. (USEPA, 1994)

Air sparging is selected to remediate the exceeded BTEX concentrations found in the groundwater because the necessary equipment is easy to obtain and install with minimal site disturbance so that remediation is commenced as soon as possible. (USEPA, 1994)

Also, air sparging has the ability for combination with other soil remediation technologies such as SVE resulting in increased remediation efficiency and minimizing the risk of migration of contaminant plume which is a concern in using air sparging by itself.

(USEPA, 1994) Since air sparging is cost effective and remediation time is relatively short (USEPA, 1994) and that Happy Valley-Goose Bay has an unconfined aquifer (NEIA, 2008) then air sparging is an optimal technology for combination with SVE to remediate the soil and groundwater.

Air sparging is selected over pump and treat because the cost of remediation are usually very high compared to air sparging. (USEPA, 1994), (Pacific Northwest National Laboratory, 1994) Also, remediation time of pump and treat is very long compared to air sparging and since there is potable drinking water contamination, pump and treat may not reach the safe required concentration levels. (USEPA, 1994), (Khan, F.I., Husain, T., Hejazi, R., 2004)

Air sparging is selected over biosparging because the indigenous microorganisms are dependent on groundwater temperature (USEPA, 1994) and that Happy Valley-Goose Bay is in a relatively cold climate than it is not recommended to implement biosparging over air sparging. Also, the microorganisms could potentially have unpredictable movement which may result in delayed remediation. (USEPA, 1994)

SVE integrated with air sparging are chosen for the optimal remediation technologies because of their combined capability to increase remediation efficiency and reduce cost in a relatively short period of time in a safe and environmentally friendly manner. (USEPA, 1994) Air sparging allows SVE to collect the injected air directed into groundwater to increase remediation efficiency in soil and to reduce the risk of unwanted soil vapours released into the environment. (USEPA, 1994)

Once remediation is commenced the site is monitored on a scheduled basis to check concentration levels and to ensure remediation is occurring at an expected rate. (ASTM, 2015) After remediation has reached its desired concentration levels then the site can return to safe conditions with no further action leaving the area with zero concerns about health and environmental issues. (ASTM, 2015)



## **Chapter 9: Conclusion**

To conclude, Risk Based Corrective Action (RBCA) was implemented to a fictional release of Total Petroleum Hydrocarbons (TPH) from a gas station underground storage tank located in Happy Valley – Goose Bay that was found to be punctured which resulted in a large quantity of TPH being released into the surrounding environment thus adversely affecting nearby soil and groundwater.

RBCA is designed in tiers, each of which includes various levels of data collection and analysis. (ASTM, 2015) As RBCA progressed then the assumptions from previous tiers are substituted with site specific data. (ASTM, 2015) Each tier's results were evaluated and reviewed to decide if more site specific data was required. (ASTM, 2015) RBCA required a site assessment, site classification, Tier 1 evaluation, Tier 2 evaluation, Tier 3 evaluation, and remedial action to reach the desired safe concentration levels. (ASTM, 2015)

Soil and groundwater samples and necessary specific site data was analyzed to calculate the severity of the TPH release around the contaminated residential and commercial sites that contained contaminants benzene, toluene, ethylbenzene, and mixed xylenes (BTEX), known to have adverse acute and chronic health and environmental effects. (ATSDR, 1999)

Tier 1 was applied where commercial and residential risk based screening levels (RBSL) were calculated using carcinogenic and non-carcinogenic RBSL's equations with default exposure parameters and default soil, building, surface, and subsurface parameters to develop a look-up table which was used to compare to the laboratory BTEX chemicals of

concern levels found in soil and groundwater at each contaminated site. (ASTM, 2015)

After comparison it was observed that commencement of Tier 2 was necessary since various locations have exceeded BTEX RBSL's.

Tier 2 was then implemented where commercial and residential site specific target levels (SSTL) were calculated using carcinogenic and non-carcinogenic SSTL's equations with collected SSTL exposure parameters and collected SSTL soil, building, surface, and subsurface parameters to develop a look-up table which was used to compare to the laboratory BTEX chemicals of concern levels found in soil and groundwater at each contaminated site. (ASTM, 2015) After comparison it was observed that commencement of Tier 3 was necessary since various locations have exceeded BTEX SSTL's.

Tier 3 of the RBCA process was integrated where the commercial and residential SSTL's were calculated using carcinogenic and non-carcinogenic SSTL's equations along with probabilistic evaluations, additional site assessment, and complicated chemical fate and transport models. (ASTM, 2015) The collected SSTL exposure parameters and SSTL soil, building, surface, and subsurface parameters are used to develop a look-up table which is used to compare to the laboratory BTEX chemicals of concern levels found in soil and groundwater at each contaminated site. (ASTM, 2015) After comparison it was observed that commencement of remedial action was necessary since various locations have exceeded BTEX SSTL's.

Finally, in the RBCA process, remedial action was utilized where potential remediation technologies were discussed to lower the site BTEX concentrations to become equal or below the Tier 3 SSTL's. (ASTM, 2015) Three soil and three groundwater remediation

technologies were explained in this stage to aid in the removal of BTEX where the optimal soil and groundwater remediation technologies are selected based on various site specific factors. The three soil remediation technologies described were soil vapour extraction, soil flushing, and bioventing. The three groundwater technologies described were pump and treat, air sparging, and biosparging.

After further review and applying the Happy Valley-Goose Bay site specific factors, soil vapour extraction (SVE) is selected for soil remediation and air sparging is selected for groundwater remediation. Also, by mutual combination of these two remediation technologies the remediation efficiency will increase (USEPA, 1994) so that the site can return to safe conditions with zero adverse risks to human health and the surrounding environment.

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